EXAMINATION OF THE HAND & UPPER LIMB

RAOUL TUBIANA

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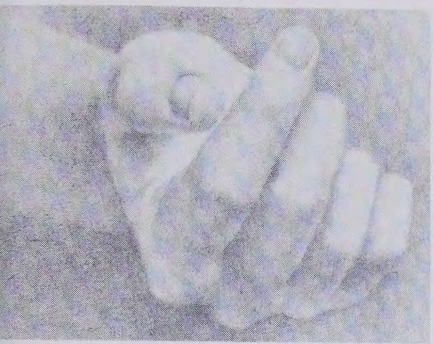
Preface

This small book is mainly composed of the text and illustrations of six pertinent chapters in Volumes I to III of *The Hand* and concentrates upon fundamental elements of the examination of the hand. There are chapters on anatomy and function, clinical examination, muscle testing of the upper limb, sensory testing, and peripheral nerve paralysis. Most of these have been significantly enhanced by the addition of numerous illustrations and some text, so that they are in general more complete and more detailed than the chapters from which they derive.

Abundant line drawings help to clarify physiologic mechanisms and testing methods. The work is intended not only for the specialist but even more for the general surgeon, neurologist, hand therapist, and student—in fact for anyone with an interest in the normal anatomy and pathology of the upper limb.

Contents



ARCHITECTURE AND FUNCTIONS OF THE HAND

Recent developments in hand surgery have come about as a result of a better understanding of the dynamic anatomy and function of the hand. This new concept of the functional rather than static anatomy is the subject of this chapter.

The hand is both an organ designed to obtain information and an organ of execution. Its very specialized anatomy expresses these functions, which are essential in our dealings with the environment. We will first discuss the architecture and then the functions of the hand.

Functional Anatomy of the Hand

The hand gives the upper limb its importance and originality. It is located at the extremity of the upper limb, which functions as its vector. The hand functions efficiently only if the proximal joints of the limb are stable and yet mobile; they are oriented so that the hand is almost always under visual control.

The hand moves within a large volume of space, the shoulder being the apex; it can reach any part of the body fairly easily because of the mobility of the shoulder as well as that of the elbow and the wrist, all operating in different planes (Fig. 1–1). The shoulder, the most mobile joint in the body, allows orientation of the upper limb, and the movements of the clavicle amplify those of the shoulder (Lanz and Wachsmuth, 1959). The arm assures projection of the limb from the trunk. The elbow, through flexion-extension movements, brings the hand closer to or moves it away from the body. Distal to the elbow, there is in effect virtually only one physiological unit. The combined movements of the wrist and forearm place the hand in a position for grasping. For gripping, the wrist is usually in flexion when close to the trunk and in extension when placed at a distance. Forearm rotation (pronation-supination) plays an important role, particularly for the alimentary function of bringing food to the mouth.

The hand's blood and nerve supplies are continuous with those of the rest of the limb. Some of its muscles, the extrinsic muscles, arise in the arm and forearm. Thus the hand must be studied as an integral part of the upper extremity.

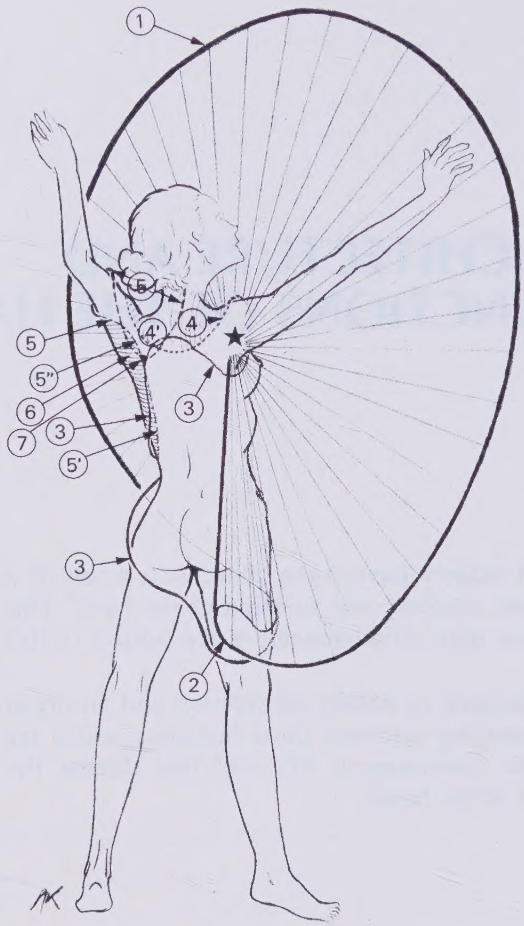


Figure 1–1. The range of movements of the upper extremity, and the body regions accessible to the right hand. The spherical section of the space centered at the shoulder is contained in the cone of circumduction (1), within which the hand may grasp an object or food and carry it back to the mouth. Its posterior aspect (2) projects slightly backward. Zones of body access (for the right upper extremity): The dorsal zone (3) is reached by the arm carried backward, downward, and inward, with the elbow flexed and the forearm pronated or supinated for the lower half and supinated for the upper half and the perineal region. The cervical-trapezius zone (4) is reached by passing to the right of the head. The contralateral cervical-deltoid zone (5) is reached by passing in front of the left side of the head. The contralateral lateral-dorsal zone (6) is reached by passing in front of the trunk. Certain zones are partially overlapping, especially zones 3, 5, and 6 at the triple point (7) of the opposite scapula, accessible with difficulty by three different routes.

The open hand, with fingers extended and in contact, forms a balanced graceful oval in its longitudinal axis. Its proximal "carpometacarpal" half is flattened, presenting two faces, each with its unique anatomical and functional significance. The back of the hand is the surface that is usually visible and therefore aesthetically important; the palmar surface, which is usually hidden, is the functional surface. The anterior volar or palmar aspect is concave and the posterior or dorsal aspect is convex. The distal half of the hand is separated into five digits, which flex toward the palm. They converge in closing—that is, they flex and adduct—and diverge in opening—that is, they extend and abduct.

The digits are unequally divided into the thumb and four fingers. The thumb has a more proximal and lateral position, allowing movement inward and outward from the palm. The four fingers are the distal extension of the carpometacarpal part of the hand and perform the movement of flexion from distal to proximal on the palm. The hinges of these movements are not at the bases of the digits, but at the thenar crease and at the transverse distal palmar crease. The digits are of different lengths. When the digits are fully extended and touching each other, the tips almost describe a regular curve, the peripheral digits being the shortest. When the digits are separated, they diverge irregularly, the web space of the thumb being the largest and deepest (Fig. 1–2). When the fingers are extended and separated, the tips of the fingers lie on the circumference of a circle whose center is the head of the third metacarpal (Littler, 1977; see Fig. 1–8).

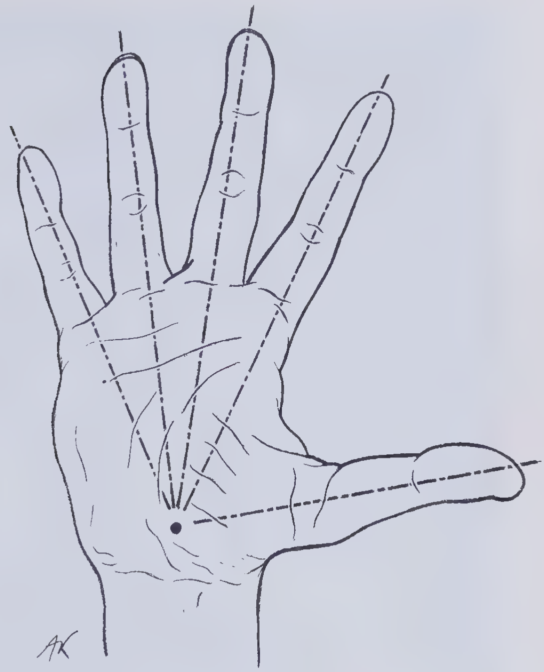


Figure 1–2. The five rays of the hand. Each is a polyarticular chain composed of a metacarpal and three phalanges, except the thumb, which has only two phalanges. When the digits are flexed separately, they converge toward a proximal point situated at the base of the palm. The thumb ray, being the shortest, is clearly separated from the fingers and is implanted proximally.

The hand is remarkably mobile and malleable, capable of conforming to the shape of objects to be grasped or studied or of emphasizing an idea being expressed. These possibilities and varieties of function are realized through the unique structure of this organ comprising 19 bones, 17 articulations, 19 muscles situated entirely within the hand, and about the same number of tendons activated by the forearm muscles.

We will consider the osseous and fibrous skeleton of the hand, the movements of the hand, the functional value of the digits, and the cutaneous covering of the hand.

THE SKELETON

We will consider first the rays of the hand and then the fixed and mobile elements of the skeleton, the arches of the hand, and the fibrous skeleton.

THE RAYS OF THE HAND

The skeleton of the hand and wrist consists of 27 bones, of which 19 are long bones. The skeleton is divided into five rays, each ray making up a polyarticulated chain comprising the metacarpals and phalanges. The base of each metacarpal articulates with the distal row of the carpus (Fig. 1–3). The carpus articulates with the skeleton of the forearm through its proximal row. The radiocarpal articulation has two axes of movement to which is added a third—pronation and supination from the forearm. Therefore, the wrist has three axes of movement, permitting the hand to be positioned in any spatial configuration and allowing it to be placed as needed for grasping.

Since the skeleton of the hand consists of five polyarticulated chains, it is susceptible to deformation. The radial or first ray, the shortest, is made up of

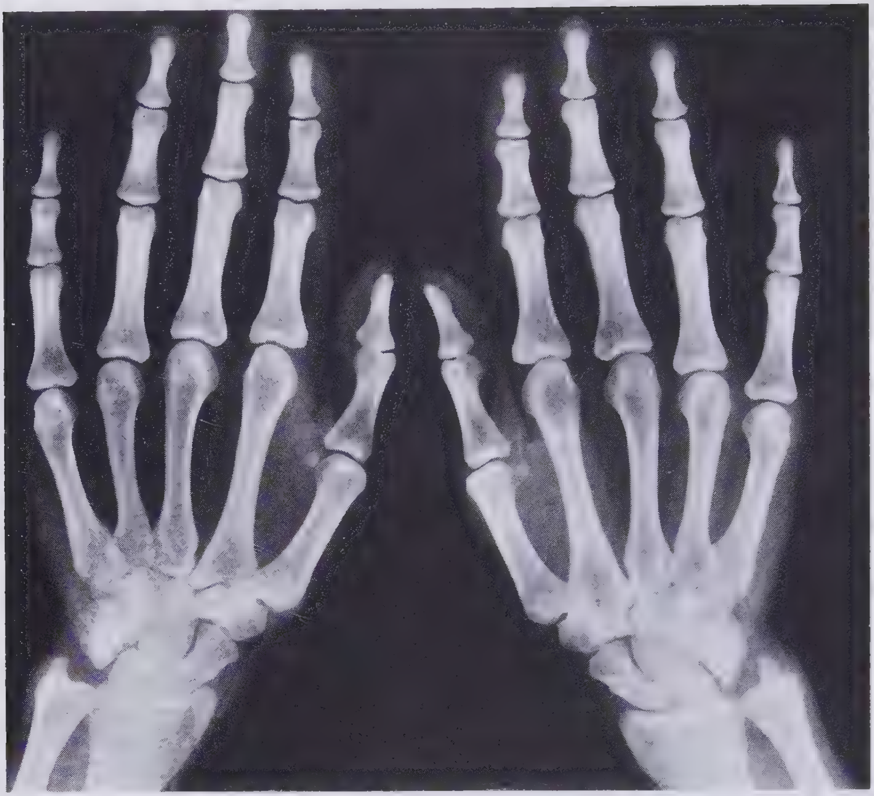


Figure 1–3. X-ray views showing the skeleton of both hands. The thumb metacarpal is the shortest and the index metacarpal by far the longest. The proximal and middle phalanges of the long and ring fingers are longer than those of the index finger. Note the interlocking design of the carpometacarpal articulations and the saddle shape in opposing planes of the articular surfaces of the trapezium and the base of the first metacarpal.

only three bones—a metacarpal and two phalanges; its considerable functional importance and originality stem essentially from its great liberty of movement. The first ray continues the external column of the carpus formed by the scaphoid and trapezium. This column is endowed with a relative autonomy owing to scapholunate mobility. Moreover, the trapezium is clearly angled out in front of the carpal plane so that the first metacarpal makes an angle of about 45 degrees with the second metacarpal in the sagittal plane. This position, along with the shape of the metacarpotrapezial joint, explains the gap between the first ray and the palm and gives the thumb metacarpal the possibility of opposing the four other digital rays (Fig. 1–4). These other rays are of unequal length, being formed by four skeletal segments—a metacarpal and three phalanges.

Precise relationships exist among the length, mobility, and position of each ray. The lengths of the metacarpals vary, the thumb metacarpal being the shortest, the index finger the longest, and the others decreasing in length from the third to the fifth digits. However, the proximal and particularly the middle phalanges of the middle and ring fingers are longer than those of the index finger so that the long finger, and usually the ring finger, are longer than the index finger. Not only does each skeletal segment and each ray have a different absolute length, but their relative lengths also vary with the movements of opening and closing the fist in such a manner that the digital extremes of each ray converge in flexion either toward the pulp of the thumb for thumb pinch

Figure 1–4. The thumb ray—more mobile, shorter, and more proximal than the others—can project in front of the plane of the palm to oppose itself to the other four rays.

or toward the base of the thenar eminence for power grip (digitopalmar grip). This convergence away from the median axis means that the more ulnar the digit, the more obliquely it must deviate as it approaches the palm (Fig. 1–5). The two ulnar metacarpals, especially the fifth, have slightly more mobility in flexion-rotation, compensating for their lack of length. The convergence of the palmar digits toward the scaphoid tubercle results from the orientation of their distal segments in flexion, and it is essentially at the level of the metacarpophalangeal and the proximal interphalangeal articulations that these deviations are produced, as demonstrated by Dubousset (1971) and Kuczynski (1975).

Thus, there is a precise relationship between the length and mobility of the thumb and the length and mobility of the rest of the fingers. This architectural relationship could be described as a positioning for grip.

The skeleton of the hand presents a longitudinal and transverse concavity, giving it the shape of a cup with a palmar concavity when the thumb is placed next to the index finger. When the thumb spreads to grasp an object, the cup becomes a gutter whose major oblique axis follows the thumb crease. It is essential for the prehensile role of the hand that these curvatures be respected in both their longitudinal and transverse axes.

The transverse axis of the palm, which corresponds to the metacarpophalangeal articulations, is not perpendicular to the longitudinal axis, represented by the median ray. Instead this transverse axis is oblique, more distal at the metacarpophalangeal joint of the index finger and more proximal at the fifth metacarpophalangeal joint. Thus it forms an acute angle of approximately 75 degrees with the longitudinal axis (Fig. 1–6). It is necessary to take this

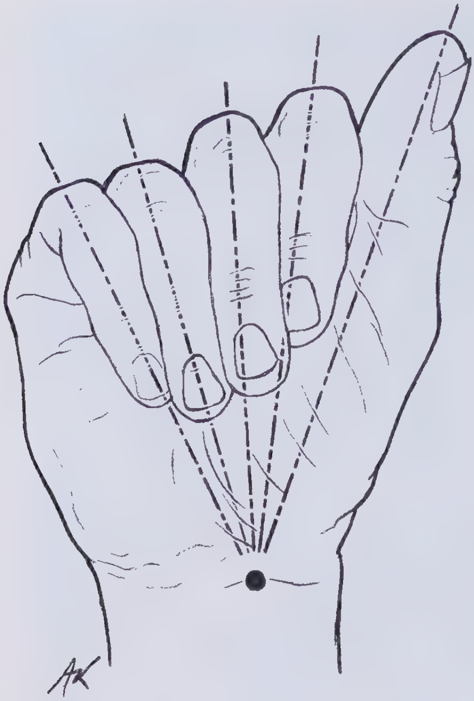


Figure 1–5. The oblique flexion of the last four digits. Only the index ray flexes in a sagittal plane. The more ulnar the digit, the more obliquely it flexes toward the median axis. Thus, when the last four digits are flexed separately at the metacarpophalangeal and proximal interphalangeal joints, their axes converge toward the scaphoid tubercle.

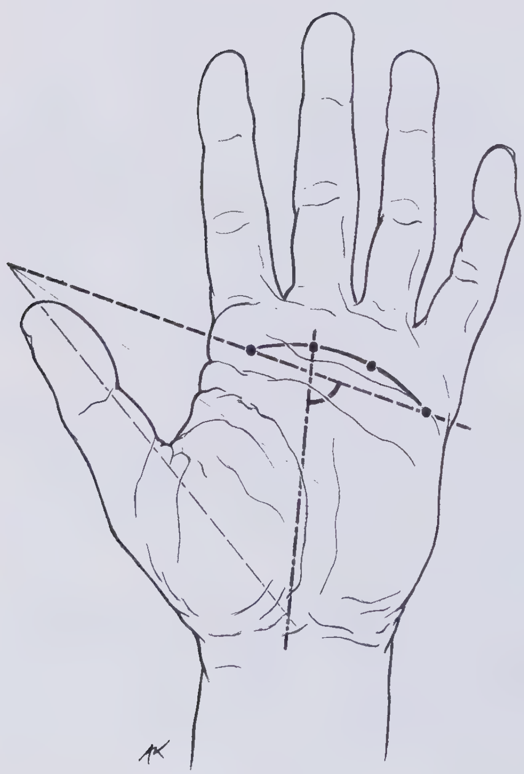


Figure 1–6. The obliquity of the transverse palmar axis. The transverse palmar axis passes along the line from the second to the fifth metacarpal head and forms an angle of 75 degrees with the axis of the third ray. The axis of the palmar groove is more oblique and follows closely the distal part of the oppositional crease of the thumb.

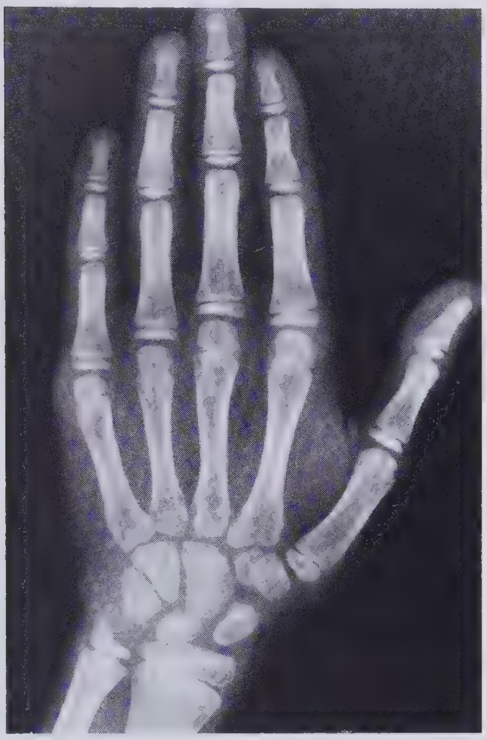


Figure 1–7. The hand of an infant. The epiphyseal plates are located at the proximal ends of the phalanges and the first metacarpal and at the distal ends of the other metacarpals.

obliquity into account in applying plaster casts or splints and also in the positioning of crutch and cane handles.

The epiphyseal plates are located at the proximal ends of all the phalanges and the thumb metacarpal, which could be considered a phalanx, whereas they are located on the distal ends of the other four metacarpals (Fig. 1–7).

FIXED AND MOBILE ELEMENTS OF THE SKELETON

One might schematically distinguish two groups in the skeleton of the hand: the fixed and the mobile elements (Littler, 1960; Fig. 1–8). The fixed elements include the distal row of the carpal bones and the attached central metacarpals. Between the different skeletal pieces composing the so-called fixed portion, the articulations are allowed some degree of independence, sufficient to insure a discrete suppleness yet permitting stability without rigidity. The mobile elements include two parts—the distal elements, the phalanges, which form the skeleton of the digits and make closure of the fingers possible, and the other part, the peripheral metacarpals, essentially the thumb and the fifth metacarpal.

THE ARCHES OF THE HAND

Usually two transverse arches—a carpal and a metacarpal arch—and one longitudinal arch are described (Fig. 1–9). To these one may also add the oblique arches of opposition between the thumb and each of the fingers (Fig. 1–10; Kapandji, 1963).

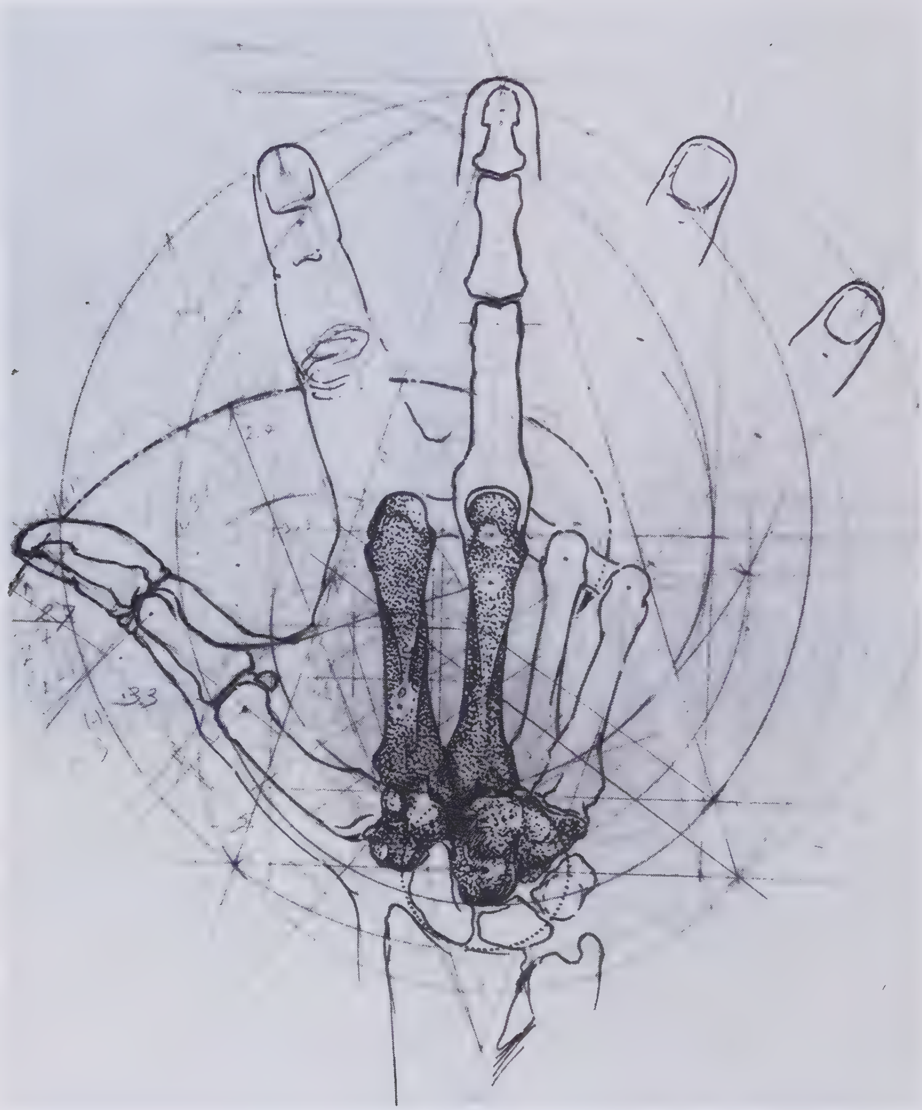


Figure 1–8. Geometric representation of the hand, by J. W. Littler. The fixed elements of the skeleton are represented by the strippled areas. In the hand, with the fingers extended and abducted, the finger tips lie on the circumference of a circle whose center is in the third metacarpal head. The circumference of this circle also runs along the articular surface of the distal radius. The carpus lies within a smaller circle whose center is the head of the capitate. The longitudinal axis of the hand passes through the middle finger, the third metacarpal, and the head of the capitate. The movements of the thumb for opposition, i.e., from extension-abduction to flexion-adduction, form a spiral equiangular curve.

The Transverse Arches

The Carpal Arch. The carpal arch has a deep palmar concavity, which at first sight resembles a rigid osseous mass sometimes incorrectly termed the "carpal block." The proximal row is mobile because of its connections to the radius and the distal row. Moreover, each of the bones that make up this row (scaphoid, lunate, and triquetrum) has its own distinct movements. The scaphoid, as it cradles the capitate, also articulates distally with the trapezium and the trapezoid and so contributes to the stability of the midcarpus.

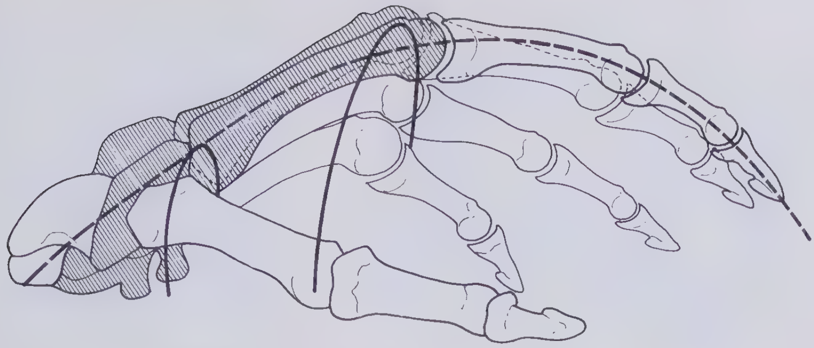


Figure 1–9. The longitudinal arches and the transverse arches of the hand, side view. The shaded areas show the fixed part of the skeleton.

The transverse arch of the distal carpal row is much more rigid. The keystone of this arch is formed by the capitate, which moves with the fixed metacarpals.

The wrist is more stable in flexion than in extension. This stability is due not so much to the interlocking of different pieces of the skeleton as to the strength of the various capsules and ligaments, structures to which we will return in studying the fibrous skeleton.

The Flexor Retinaculum. The flexor retinaculum distal to the radial joint forms a roof over the carpal gutter and transforms it into a tunnel (Fig. 1–11). Its role in effecting stability of the wrist is questionable. The massive and powerful finger flexor tendons are retained close to the axes of flexion-extension and medial-lateral deviation by the flexor retinaculum. In this way the flexors generate almost no torque at the radiocarpal joint while acting in the digits. These tendons, along with the median nerve, are sheathed by their synovial sheaths as they enter the carpal tunnel (Fig. 1–12). The narrowness of this osteofibrous tunnel explains the frequency of syndromes of irritation and compression of the median nerve. The nerve, which is more superficial than the tendons, is compressed by them when the wrist is in the flexed position (Phalen's sign; Phalen, 1951).

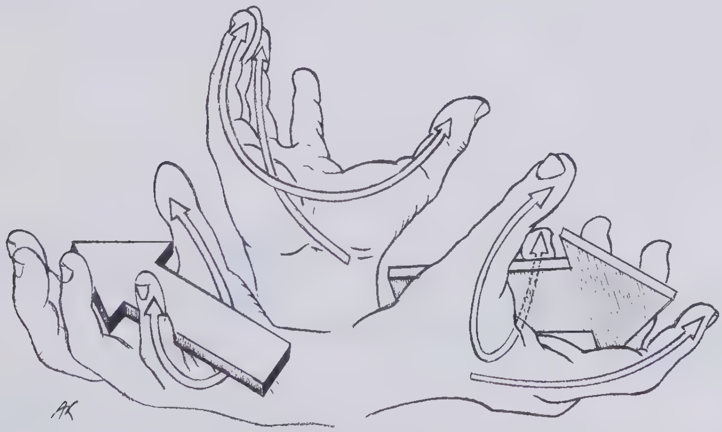


Figure 1–10. The thumb forms with the other digits four oblique arches of opposition. The most useful and most functionally important arch is between the thumb and the index finger for precision grip. The farthermost arch, between the thumb and little finger, insures a locking mechanism on the ulnar side of the hand in power grips. (After Kapandji, A. I.: Physiologie Articulaire. Paris, Librairie Maloine, 1963, Vol. 1.)

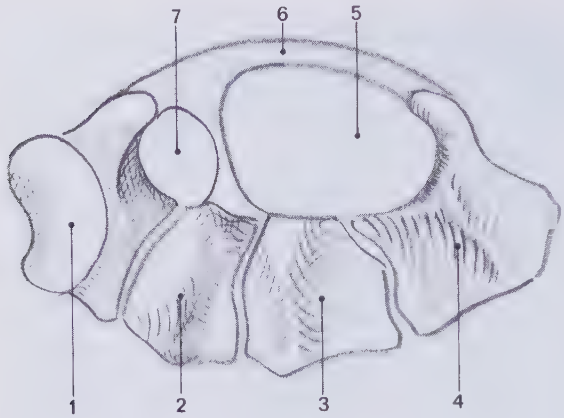


Figure 1–11. The carpal canal. The carpal groove with an anterior concavity is formed into an osteofibrous tunnel by the flexor retinaculum, which inserts on its two borders. The tunnel is subdivided into two parts by a sagittal septum that separates the carpal canal proper, situated medially and containing the flexor tendons and the median nerve, from the lateral tunnel containing the tendon of the flexor carpi radialis. 1, Trapezium. 2, Trapezoid. 3, Capitate. 4, Hamate. 5, Carpal tunnel. 6, Flexor retinaculum. 7, Tunnel for flexor carpi radialis.

The Metacarpal Arch. The metacarpal arch, by contrast, is endowed with a great deal of adaptability because of the mobility of the peripheral metacarpals. These peripheral metacarpals form the sides of the cup or the palmar gutter and can deepen the concavity as they approach each other, both being attached to the fixed element, i.e., the middle metacarpals (Fig. 1–13).

The thumb metacarpal is independent and articulates with the trapezium. The middle metacarpals are united to the carpus by the intrinsic interlocking encasement of the bones themselves. The index metacarpal is the most firmly fixed. The ring metacarpal is a transitional element to the fifth metacarpal and has about 10 degrees of mobility in flexion and extension. The fifth metacarpal is semi-independent; it articulates with the hamate and is restrained on its radial side by its articulation with the base of the fourth metacarpal. It has a range of flexion-extension of approximately 20 degrees (Fig. 1–14), which is well utilized and increases when one does a phalangization (Tubiana and Roux, 1974). Metacarpals II to V are all bound together by various fibrous structures, the most distal of which is the deep transverse intermetacarpal ligament. This ligament is better named the interglenoid ligament, because it ties together the anterior "glenoid ligaments" of the metacarpophalangeal articulations known as the "volar plates."

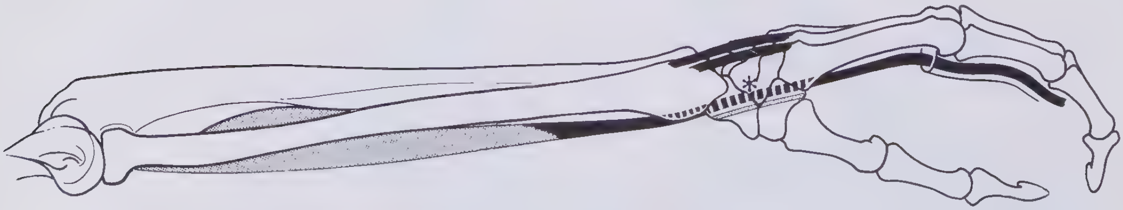


Figure 1–12. The flexor retinaculum (stippled) maintains and restrains the tendons of the extrinsic flexors of the digits within the carpal canal. Thus, these palmar tendons and especially the profundus are kept close to the axis of flexion-extension of the wrist. The extensors of the wrist, although less powerful than the flexors digitorum, are more distant from the axis of flexion-extension and therefore have a mechanical advantage that compensates for the difference in power and enables them to act synergistically with the flexors in the power grip.

Figure 1–13. The hollow or concavity of the palm depends on changes in position of the transverse metacarpal arch. These changes are accomplished by flexion and adduction movements (in relation to the axis of the hand) of the first and fifth metacarpal heads, which increase the concavity of the arch. The heads of the second and third metacarpals are fixed.

The Longitudinal Arches

The longitudinal arches are composed of a fixed portion, the carpometacarpal, and a mobile portion, the digits (Fig. 1–15). The keystones of these arches are the metacarpophalangeal articulations, whose thick anterior glenoid capsules, the volar plates, prevent hyperextension. We have just mentioned that the volar plates are interconnected by the transverse interglenoid ligament (Fig. 1–16). Thus the stability of the metacarpophalangeal joints is essential to the support of the longitudinal arch as well as of the transverse metacarpal arch. For every ray there is a longitudinal arch. They diverge distally according to their different obliquities, the thumb ray being the most divergent.

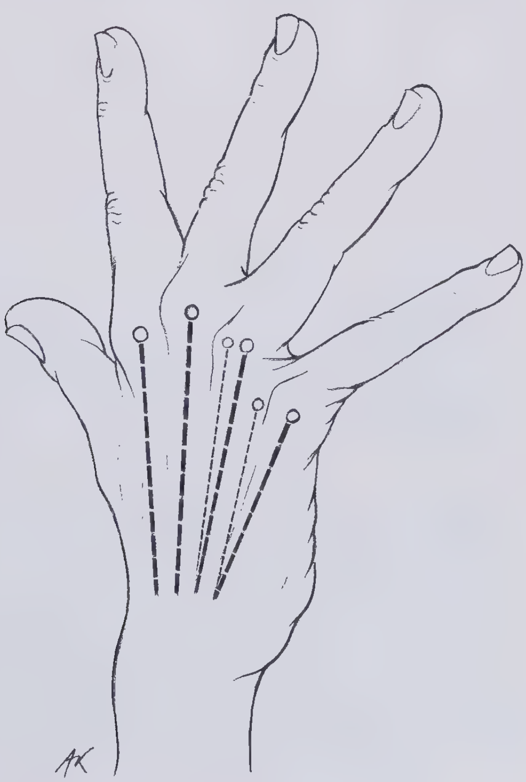


Figure 1–14. The mobility of the ulnar metacarpals. Only the fourth and fifth metacarpals are mobile at their carpal articulation, allowing "flexion" of 10 degrees for the fourth and 20 degrees for the fifth, accompanied by a slight lateral rotational movement in the longitudinal axis of the hand.

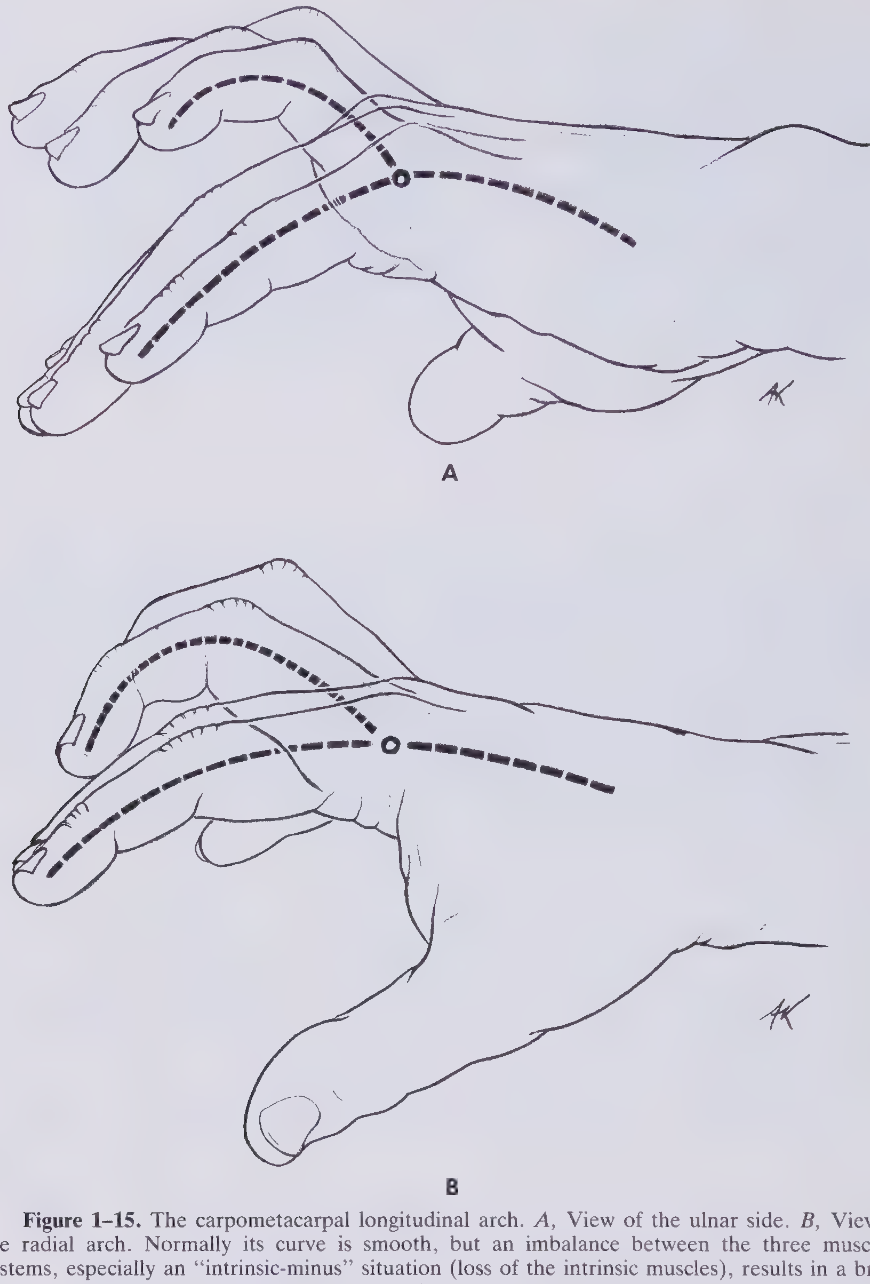


Figure 1–15. The carpometacarpal longitudinal arch. *A,* View of the ulnar side. *B,* View of the radial arch. Normally its curve is smooth, but an imbalance between the three muscular systems, especially an "intrinsic-minus" situation (loss of the intrinsic muscles), results in a break in the continuity of the curves at the level of the metacarpophalangeal joint, considered to be the keystone of this arch.

The five rays of the hand differ in mobility and independence, which are considerable for the thumb, much less for the fifth ray, and even less for the others. However, the index ray has a certain degree of independence, not at the metacarpal level, which is fixed, but at the phalangeal level, owing to the arrangement of its flexor and extensor muscles.

Working with the thumb, the index finger manipulates objects with dexterity. However, there is a specialization of the radial and ulnar rays (Fig. 1–17). The two ulnar digits customarily act together, especially in a palmar grip, to provide support and static control. The radial digits have a rather

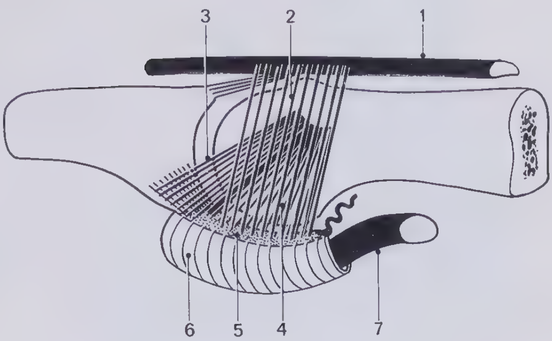


Figure 1–16. Schematic view of the metacarpophalangeal joint, keystone of the longitudinal arch of the hand. This joint is stabilized by the collateral ligaments and by the thick volar articular capsule, the volar plate, on which the lateral accessory ligaments, the sagittal bands of the extensor apparatus, and the first annular segment of the pulley of the flexor tendons insert. 1, Extensor tendon. 2, Sagittal band. 3, Collateral ligament. 4, Accessory collateral ligament. 5, Volar plate. 6, Flexor tendon sheath. 7, Flexor tendon.

dynamic action; the thumb and the index and middle fingers working together form the elements of the "dynamic tripod" for precision handling (Capener, 1956); this could be better named the "dynamic tridactyl" (Fig. 1–18). This specialization of the digits is by no means absolute: the middle finger especially, owing to its position, can be integrated with the index finger for opposition to the thumb in precision grip, or it can be integrated with the ulnar digits in a power grip.

THE FIBROUS SKELETON OF THE HAND

The osseous skeleton is complemented by a fibrous skeleton that reinforces it while allowing considerable adaptability; the fibrous skeleton comprises the aponeuroses, ligamentous structures, and fibrous sheaths attached to the bones and to the dermis.

Figure 1–17. The three functional zones of the hand. (I) The thumb, master digit of the hand, represents the dominant element, which gives value to all the others. (II) The highly mobile index and middle fingers participate in precision grips separately or together with the thumb. They play a dynamic role. (III) The ring and little finger generally work together with the others in power grips against the palm. They have a more static role and often remain "in reserve."

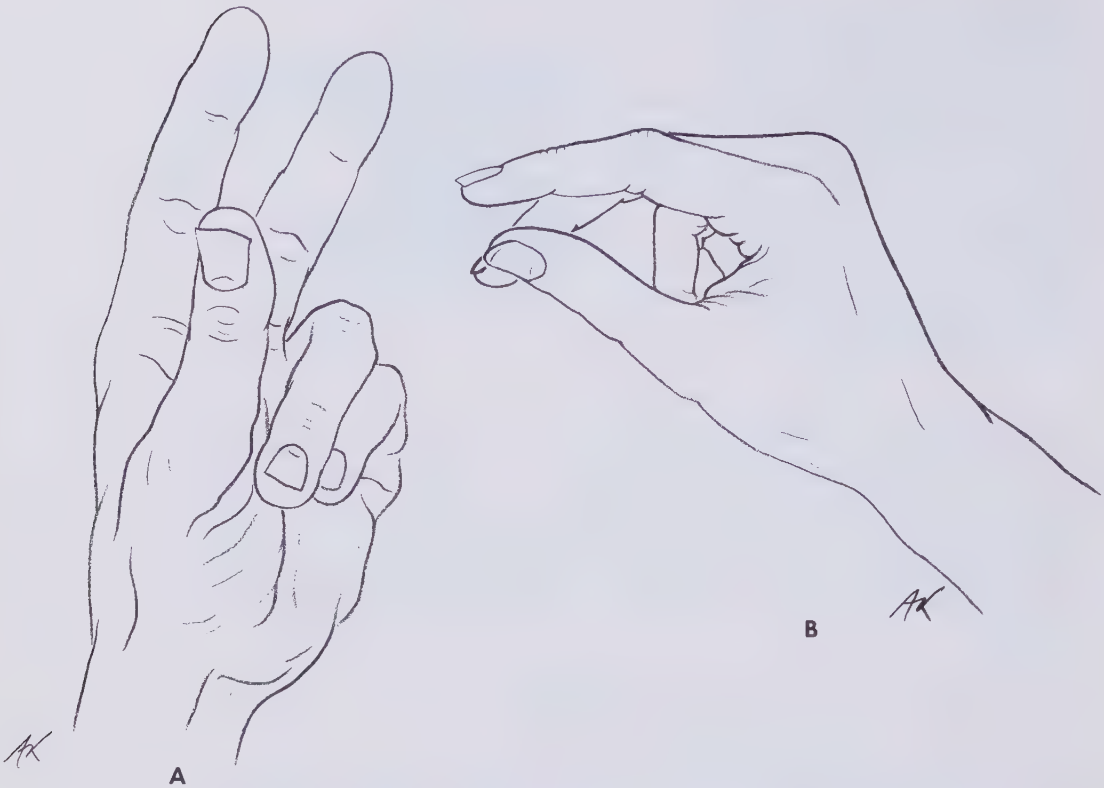


Figure 1–18. The tridactyl configuration. The first three digits work in close synergy for most grips not requiring force. This functional configuration, often utilized, constitutes, according to Capener, the "dynamic tripod."

The Superficial Palmar Fasciae

The superficial palmar fasciae stretch between the flexor retinaculum, which forms their proximal boundary, and the root of the fingers, which is their distal limit.

The central zone is anatomically and pathologically the most important. This is the palmar aponeurosis, which roofs the compartment of the hand where the flexor tendons and neurovascular bundles diverge. It forms an aponeurotic triangle with its apex proximally, the ulnar border coinciding with the hypothenar muscles and the radial border with the lateral thenar muscles (Figs. 1–19 to 1–21). It is best studied in the context of Dupuytren's contracture.

The lateral palmar fascia (or thenar aponeurosis) consists of a thin sheet of connective tissue that covers the thenar muscles. It stretches from the radial border of the first metacarpal, over the opponens and abductor pollicis brevis, in a plane that is nearly frontal. It then runs sagittally and insinuates itself between the flexor pollicis brevis and the common flexor tendons to reach the adductor pollicis muscle. Running once more in a frontal plane, it provides a lining for the adductor pollicis, which it separates from the flexor tendons. It then finds an attachment on the anterior border of the third metacarpal close to the metacarpal insertions of the transverse fibers of the adductor pollicis.

The medial palmar fascia (or hypothenar aponeurosis) is also a slender sheet of connective tissue lining the hypothenar muscles. Attached medially to the pisiform and medial border of the fifth metacarpal, it stretches in a more

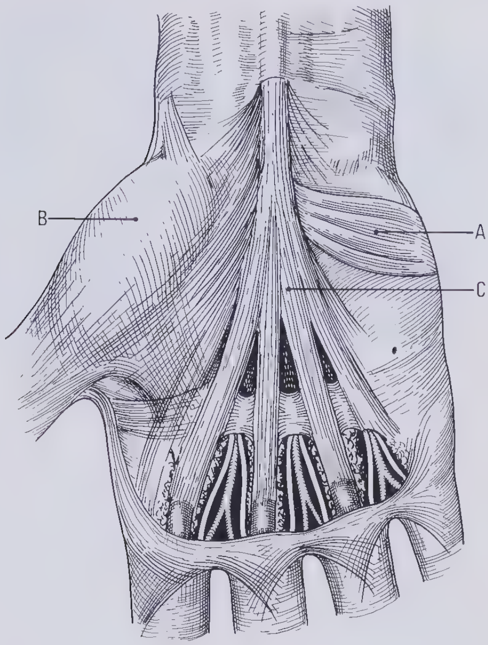


Figure 1–19. Superficial palmar aponeuroses. A, Middle palmar aponeurosis. B, Thenar palmar aponeurosis. C, Hypothenar palmar aponeurosis partly concealed by flexor digiti minimi brevis.

or less frontal plane to provide a covering for the opponens, abductor brevis, and flexor brevis digiti minimi. Becoming gradually more sagittal, it slips between the latter muscle and the common flexor tendons. It then becomes attached to the hook of the hamate and the anterior border of the fifth metacarpal anteromedially in relation to the insertions of the fourth palmar interosseous muscle.

The Deep Palmar Aponeurosis

The deep palmar aponeurosis lines the anterior aspect of the interosseous muscles and metacarpals, to each of which it is connected. Its transverse

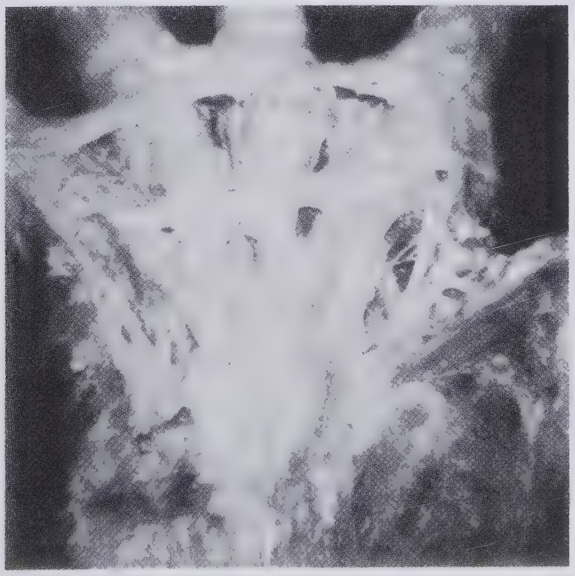


Figure 1–20. Superficial palmar aponeurosis. Note the longitudinal fibers in front of the tendons and the two transverse ligaments; the proximal ligament is called superficial (actually these fibers are deep in comparison to the longitudinal fibers) and the distal transverse ligament, commissural (or natatory).

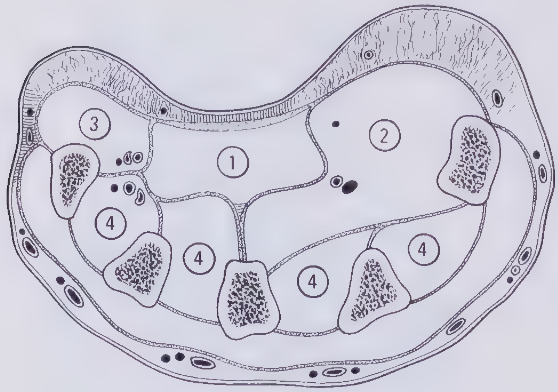


Figure 1–21. Palmar septa. 1, Middle palmar septum. 2, Thenar or lateral palmar septum. 3, Hypothenar or medial palmar septum. 4, The four interosseous septa.

continuity is broken, however, opposite the third metacarpal by the insertion of the transverse fibers of the adductor pollicis. It is weak and thin proximally, but its lower part merges with the transverse intermetacarpal ligament, which is itself anchored to the fibrocartilages of the metacarpophalangeal joints. It is connected to the superficial palmar aponeurosis by the fascial septa that divide the midpalmar space.

The Palmar Compartments

The palmar compartments are defined in terms of the various fascial septa.

The midpalmar space is bounded superficially by the palmar aponeurosis; posteriorly it corresponds to the deep palmar fascia opposite the last two intermetacarpal spaces, while laterally it corresponds to the adductor muscle, which is lined by the corresponding portion of the thenar fascia. It is bounded medially by the hypothenar aponeurosis and laterally by the thenar aponeurosis. It contains the superficial and deep common flexor tendons and their sheaths, the superficial palmar arch, and the digital vessels and digital nerves.

The lateral palmar space, or thenar compartment, is limited posteriorly by the deep palmar fascia of the two first interspaces and anteriorly by the thenar aponeurosis. It contains the four thenar muscles and the tendon of the flexor pollicis and its sheath.

The medial palmar space, the smallest, lies in front of the fifth metacarpal, which makes up its floor. It is closed anteriorly by the medial (or hypothenar) palmar fascia and contains the three hypothenar muscles.

The interosseous space consists in fact of four compartments separated by the metacarpals, each one having as its posterior wall the deep dorsal fascia. They each contain the interosseous muscle of the corresponding space.

The Dorsal Aponeuroses

The superficial dorsal fascia is a thin subcutaneous sheet, which lines the superficial aspect of the extensor tendons. Proximally it merges with the extensor retinaculum. It stretches across from the first to the fifth metacarpal.

The deep dorsal fascia, a slender cellular network, lines the dorsal aspect of the metacarpals and interosseous muscles. Between these two sheets is contained a cellular gliding space through which run the extensor tendons.

Functions of the Fibrous Skeleton

The fibrous skeleton of the hand has multiple important functions:

Stability. The fibrous skeleton plays an essential role of support in uniting bone segments and stabilizing the transverse and longitudinal arches of the hand. Each of the five rays contains three segments, which are mobile within certain limits. To stabilize one of these requires three supports—two collateral ligaments and one volar plate for each joint—which means 45 stays necessary for the five rays (Moberg, 1976).

The Volar Plates. The volar plates reinforce the capsules of the digital joints anteriorly. They are thick and resistant and have a firm distal insertion on the anterior aspect of the base of the phalanges (Fig. 1–22). This insertion is thicker in its middle part, adjacent to the bone. The proximal insertion is supple and thin and allows the movement of flexion-extension. The thickness of the volar plates increases the distance between the flexor tendons and the axis of the joint and thus improves the efficiency of the flexors. The main function of this reinforcement of the anterior capsule is to prevent hyperextension.

The range of extension varies from joint to joint. Owing to the presence of two firm lateral check attachments proximally (Eaton, 1971), the volar plate limits extension in the proximal interphalangeal joint more than in the other digital joints. It is essential that the middle phalanx never be hyperextended; this position triggers a zig-zag (swan-neck) deformity and severely impairs function. The two proximal attachments of the volar plate of the proximal interphalangeal joint insert into the proximal phalanx on each side of the flexor tendons and blend with their fibrous sheath. By contrast, some hyperextension is possible at the metacarpophalangeal and distal interphalangeal joints. This accounts for the fact that resistance to rupture is three times greater at the proximal interphalangeal joints than at the metacarpophalangeal joints (16 to 21 kg. for the proximal interphalangeal joint and 5 to 8 kg. for the metacarpophalangeal joint, according to Weeks and Wray [1973]). There is also a significant difference in physiological extension from person to person and from race to race.

The Deep Transverse Intermetacarpal Ligament. The deep transverse intermetacarpal or interglenoid ligament connects the volar plates of the metacarpophalangeal joints. This ligament is attached at its extremities to the first dorsal interosseous muscle, which inserts on the radial border of the volar plate of the index finger, and to the abductor digiti minimi, which inserts on the ulnar border of the volar plate of this digit (Fig. 1–23).

The Deep Dorsal Aponeurosis. The deep dorsal aponeurosis, which inserts on the four ulnar metacarpals, forms a true posterior intermetacarpal ligament.

Fixation of the Skin. Fixation of the skin is found in the zones of prehension in the palm (dermal insertions of the superficial palmar aponeurosis) and in the

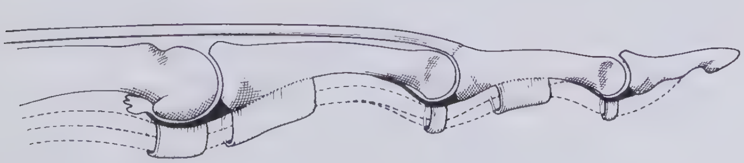


Figure 1–22. The three volar plates of the fingers and the five annular portions (pulleys) of the flexor tendon's fibrous sheath.

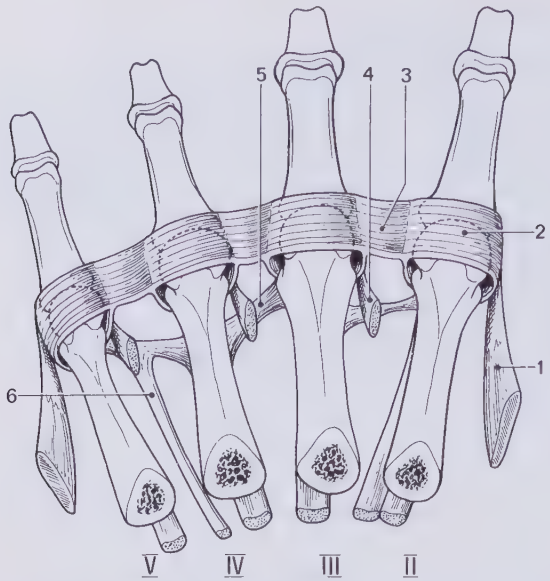


Figure 1–23. The fibrous skeleton of the transverse metacarpophalangeal arch. The metacarpophalangeal arch is supported by the extremely important fibrous skeleton. It is formed in front by the thick anterior capsular reinforcements of the metacarpophalangeal joints (or volar plates) joined together by the deep transverse metacarpal ligament (also called the interglenoid ligament). On the dorsal aspect the long extensor tendons are joined together by the juncturae tendinum (conexus intertendineus). The common extensor digitorum sends to each side of the joint the sagittal bands that insert on the interglenoid ligament. This fibrous skeleton is tightened by the intrinsic muscles, in particular by the first dorsal interosseous muscle on the radial side and by the abductor digiti minimi on the ulnar side. 1, First dorsal interosseous muscle. 2, Volar plate. 3, Intermetacarpal ligament. 4, Interosseous muscle. 5, Conexus intertendineus. 6, Extensor digitorum communis tendon.

digits (Cleland's ligaments, dermal insertions of the fibrous structures in the finger pulp).

Containment. The superficial palmar aponeurosis, digital aponeurosis, and dorsal aponeurosis insure containment of the structures of the hand.

Partition. The deep palmar aponeurosis and septa separate the hand into compartments.

Protection and Padding. The fibrous meshwork is found in the subcutaneous tissue of the distal part of the palm in front of the metacarpal heads, in the hypothenar eminence, and in the finger pulp.

Connection. The transverse interglenoid ligament, or deep intermetacarpal ligament, connects the volar plates. The juncturae tendinum, or connexus intertendineus, connect the extensor digitorum communis tendons.

Coordination. The oblique retinacular (Landsmeer's) ligaments provide coordination between the interphalangeal joints of the fingers.

Tendon Guidance. The various digital fibrous sheaths of the flexor tendons prevent the tendons from bowstringing as they cross the individual joints. The retinacula of the wrist are palmar and dorsal. The flexor retinaculum, as already stated, inserts on the carpal bones, whereas the extensor retinaculum inserts proximally on the distal end of the radius. This dorsal structure has six compartments for the tendons of the muscles of the posterior compartment of the forearm (see Fig. 1–26). All these features keep the tendons applied against the skeleton and permit their changes of direction at the level of the reflexion pulleys. They also contribute to the stability of the wrist and fingers.

Restraint. Restraint is provided by the sagittal bands of the common extensor and the check rein ligaments of the volar plates.

This complex fibrous apparatus allows each segment of the digit to have great freedom of movement, to be stable, to remain within a small volume, and to be highly mobile without the need for muscle bellies.

During active utilization of the hand, the fibrous skeleton has zones of condensation, kept under tension by a balance of forces exerted in different

directions. Thus, the fibrous skeleton has not only distinct important anatomical components, but in a functional sense has balance and equilibrium in its dynamics. Zancolli (1979) has especially emphasized that this assemblage of fibrous structures on each side of the palmar surface of the metacarpophalangeal articulations forms a true fibrous nucleus (force nucleus; Fig. 1–24). Indeed, the structures converging toward this nucleus are multiple—the deep transverse intermetacarpal ligament, the anterior articular capsule (the volar plate), the sagittal bands of the extensors, the proximal portion of the proximal flexor pulley (A_1), and the accessory collateral ligaments of the metacarpophalangeal joints. If this fibrous complex is destroyed or simply displaced, as for example by distention of the metacarpophalangeal joint, a condition frequently seen in rheumatoid arthritis, the balance of forces converging at this level will be disturbed, the transverse arch will flatten, the finger will be deformed, and its function will be compromised.

At the level of the proximal interphalangeal joint a similar fibrous arrangement can be seen. In front the fibrous flexor tendon sheath is suspended from the volar plate. Laterally Cleland's ligaments are attached to the skin, and the oblique retinacular ligaments cross the joint obliquely, while the transverse fibers of the retinacular ligament are the more superficial.

THE FIBROUS SKELETON OF THE WRIST

The fibrous skeleton of the wrist is of particular importance because stability and mobility of the wrist are indispensable to good hand function. The stability of the radiocarpal and midcarpal articulations is assured in part by the slings formed by the extrinsic tendons of the wrist and fingers. They add a dynamic reinforcing action to the passive capsuloligamentous restraints.

The ligaments of the wrist are oriented so as to resist an anteromedial force. In the radiocarpal articulation, the distal radial surface is biconcave. In the lateral view shown in Figure 1–25 there is a 12 degree palmar tilt, and in the anteroposterior view there is approximately a 15 degree medial angulation.

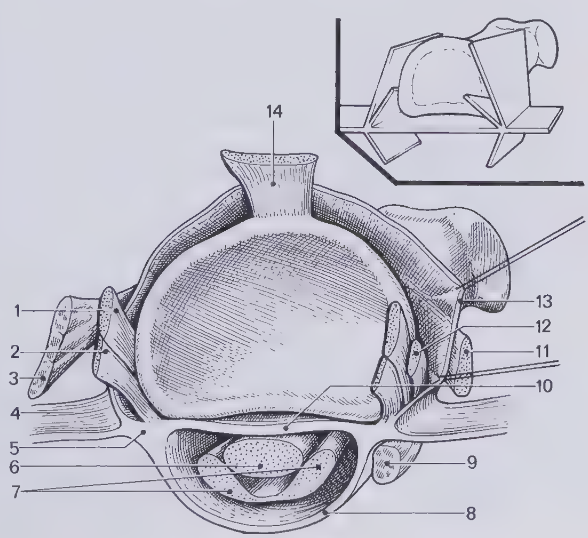


Figure 1–24. The fibrous nucleus (force nucleus of Zancolli) is located on each side of the palmar aspect of the metacarpophalangeal articulation and is formed by the convergence of the transverse interglenoid ligament, the volar plate, the sagittal bands, the fibrous flexor tendon sheath, and the lateral accessory metacarpoglenoid ligaments. 1, Collateral ligament. 2, Accessory collateral ligament. 3, Interosseous muscle. 4, Intermetacarpal ligament. 5, Fibrous nucleus. 6, Flexor digitorum profundus. 7, Flexor digitorum superficialis. 8, Flexor tendon sheath. 9, Lumbrical muscle. 10, Volar plate. 11, Interosseous muscle. 12, Insertion of interosseous muscle into base of phalanx. 13, Sagittal band. 14, Central slip of extensor tendon inserting on base of proximal phalanx.

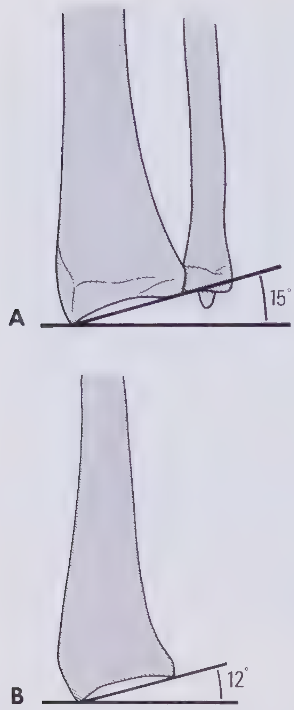


Figure 1–25. The biconcave articular surface of the distal end of the radius. *A*, Anteroposterior view. A line joining the end of the radial styloid and the ulnar border of the distal end of the radius forms an angle with the horizontal of approximately 15 degrees that opens medially. *B*, Side view. The posterior margin of the distal end of the radius forms with the anterior rim a 12 degree angle that opens forward.

The posterior lip and the radial styloid thus have a buttressing effect. The carpal condyle is situated in the relatively unstable glenoid cavity of the distal radius-ulna, and its stability is fully dependent on the fibrous skeleton. The structure and orientation of the lower radius explain why the dorsal fibrous elements are weaker than the palmar ones and are more easily ruptured or stretched; their action is reinforced by the strong extensor retinaculum that wraps around the triquetrum. Moreover, the principal ligaments have a general orientation from the radius distally and medially. One can say that the carpus keeps its position on the radius because of its fibrous skeleton.

The ulnar head, which is placed more proximally than the radial styloid, is not truly a part of the wrist. It plays only an indirect role in the stability of the wrist, essentially through the triangular ligament, the ligaments of the distal radioulnar joint, and the weak ulnar triquetral ligament.

The principal elements of wrist restraint are volar (Fig. 1–26). From the lateral part of the radius comes the radial collateral ligament, which courses on the volar surface from the anterior margin of the tip of the radial styloid to the tuberosity of the scaphoid and trapezium. The volar radiocarpal ligaments are the main ligaments from the lateral aspect of the radius. The two most important ones are both oblique, one proximal and one distal. The proximal ligament arises from the styloid process of the radius and passes over the proximal part of the scaphoid and lunate to insert into the triquetrum. The distal ligament arises from the margin of the radial styloid and crosses the waist of the scaphoid; it inserts mainly into the capitate. This ligament acts as a sling to enable the scaphoid to pivot around it. As Verdan (1954) has pointed out, in pronation-to-supination movements this ligament presses on the scaphoid; for this reason he recommends that the elbow be immobilized in cases of fracture of the scaphoid.

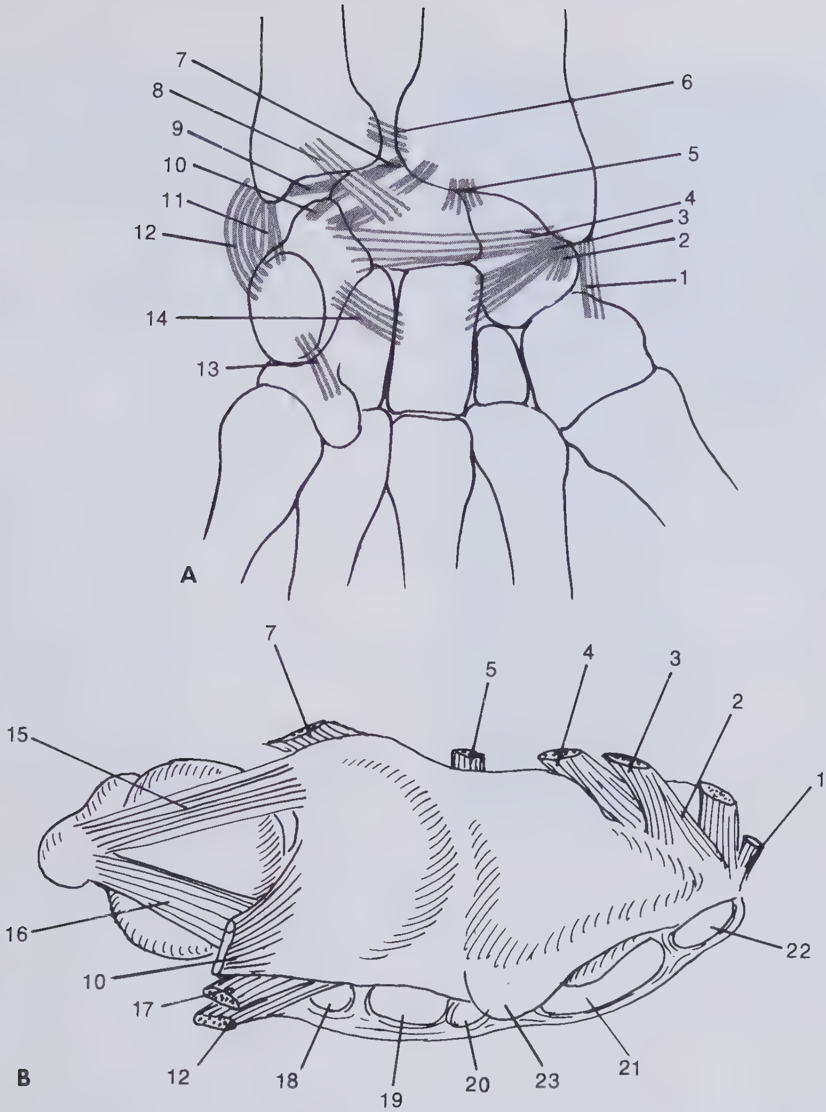


Figure 1–26. The ligaments connecting the carpus to the forearm skeleton. *A*, Palmar view of the ligaments of the wrist. *B*, Distal view of the radius and ulna. 1, Radial collateral ligament. 2, Radioscaphoid band of the palmar radiocarpal ligament. 3, Radiocapitate band of the same ligament. This band runs across the waist of the scaphoid and is the strongest ligamentous feature in the wrist. Verdan (1954) noted that during pronosupination, the band compresses the scaphoid. He advocates, therefore, the immobilization of the elbow in a long arm plaster in fractures of this bone. 4, Radiotriquetral band of the palmar radiocarpal ligament. The space between the last two bands corresponds to the articular space between the lunate and the capitate, a weak point on the anterior ligamentous complex. 5, The radioscapholunate ligament. 6, Palmar ligament of the distal radioulnar joint. 7, Palmar radiotriquetral ligament (the anterior leg of Kuhlmann's sling). 8, Ulnotriquetral band of the palmar ulnocarpal ligament. 9, Radioulnar triangular fibrocartilage. 10, Radiotriquetral meniscus. 11, Ulnar collateral ligament. 12, Extensor retinaculum. 13, Pisohamate ligament. 14, Palmar triquetrocapitate ligament. 15, Anterior pillar of the triangular fibrocartilage. 16, Posterior pillar of the triangular fibrocartilage. 17, Radiotriquetral band of the dorsal radiocarpal ligament (the posterior leg of Kuhlmann's sling). *B* shows the compartments for the tendons of the extensor digiti minimi (18), the extensor digitorum and extensor indicis (19), the extensor pollicis longus (20), the extensores carpi radiales (21), the extensor pollicis brevis and abductor pollicis longus (22), and the dorsal tubercle of the radius (23; Lister's tubercle).

These diagrams stress the following points: (1) The ulnar head plays only an indirect role in the stability of the wrist. (2) The carpus is suspended on the radius by means of the radiocarpal ligaments. (3) The fibers of these ligaments are oriented in an oblique general direction distally and ulnarward. (4) The internal stability of the radiocarpal complex is secured from deep to superficial by the triangular fibrocartilage and the radiotriquetral meniscus; the anterior and posterior radiotriquetral ligaments ("Kuhlmann's sling"); and the peripheral sling formed by the radiocapitate band of the palmar radiocarpal ligament, the palmar triquetrocapitate ligament, the pisohamate ligament, and the extensor retinaculum.

There is a gap between the proximal and distal ligaments that corresponds to the joint between the capitate and lunate (Poirier and Charpy, 1926). Synovium is often seen to bulge out at this point in rheumatoid disease, and, because there is usually no interosseous ligament between the capitate and its lunate, injury or dislocation is more likely to occur. Congenital or acquired ligament laxity predisposes to instability in this region (Fisk, 1970).

The principal elements of ulnar carpal restraint are formed by the anterior and posterior ulnar tendons and by the medial radiocarpal ligaments. Among the latter, Kuhlmann (1977) describes a "frondiform ligament" made up of a palmar radiotriquetral ligament and a dorsal radiotriquetral ligament. This forms a harness around the ulnar side of the carpus (Fig. 1–26).

Taleisnik's descriptions of these medial radiocarpal ligaments differ in several points (Taleisnik, 1976). He describes a meniscus between the radius and triquetrum, which has a common origin with the triangular fibrocartilage ligament from the dorsoulnar corner of the radius. From here the meniscus swings around the ulnar border of the wrist to insert into the triquetrum (Fig. 1–27*B*).

Regardless of which of the foregoing descriptions is correct, it is this sling arrangement that we attempt to reconstruct to resist ulnar and volar deforming forces.

The radioscapholunate ligament of Testut and Latarjet (1928) has a longitudinal axis and makes the smallest contribution to wrist stability, although it contains numerous blood and lymph vessels and can be involved in diseases such as rheumatoid arthritis (Mannerfelt and Raven, 1978; Fig. 1–27*A*). The insertions to the scaphoid and lunate are of different lengths to allow for their respective displacements in movement.

All these ligaments originate outside the carpus and therefore can be described as extrinsic ligaments; additional stability is given by the intercarpal or intrinsic ligaments (Taleisnik, 1976).

Knowledge of the different elements of the fibrous skeleton of the wrist is indispensable in understanding the physiology of this articular complex and in treating fractures, subluxations, or sprains of the wrist as well as the secondary deformations of traumatic, rheumatic, or other arthropathies in a rational way.

THE MOVEMENTS OF THE HAND

The hand is essentially a mobile organ. It can coordinate an infinite variety of movements in relation to each of its elements. This blending of movements of the wrist and digits allows the hand to mold itself to the shape of the object for palpation or grasp. We will consider the factors involved in the mobility of the hand and the movements of each functional unit of the hand.

FACTORS INVOLVED IN MOBILITY

The great freedom of movement of the hand is due to the gliding mechanisms, the articular system, and the muscles.

The Gliding Mechanism

Most of the structures in the hand glide in relation to the neighboring structures.

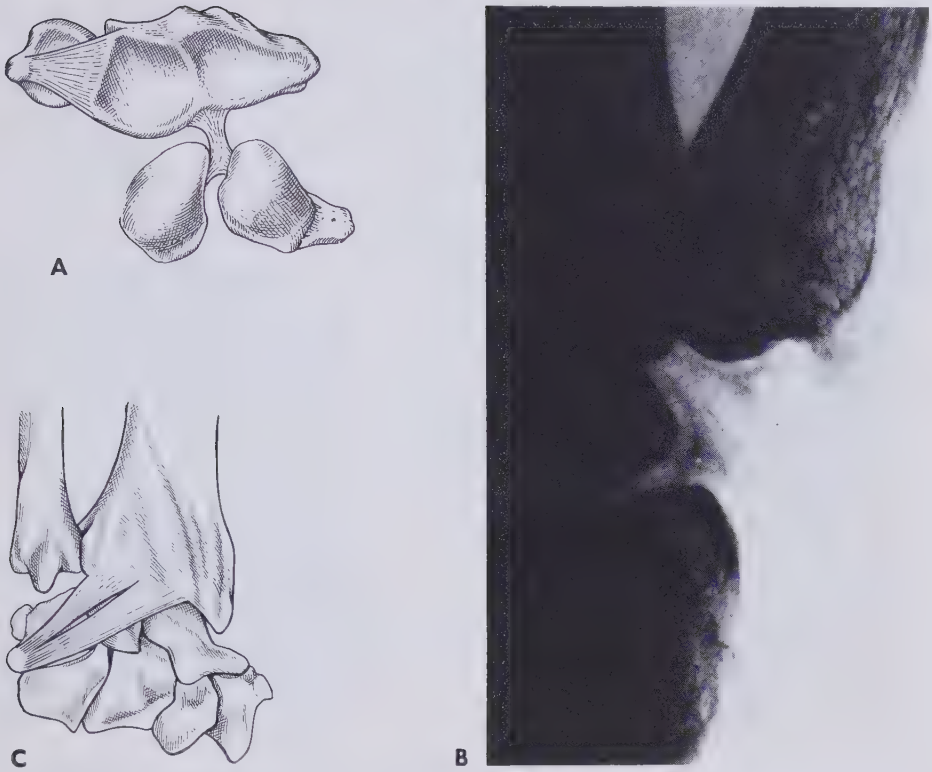


Figure 1–27. Some less well known details of the ligaments of the wrist. *A,* The radioscapholunate ligament transmits blood vessels to the two carpal bones (Testut and Kuenz, 1923). The radioscaphoid fibers, longer than the radiolunate ones, allow for the differences in the range of movement of these bones. *B,* A case of chondrocalcinosis. The triangular fibrocartilage complex is calcified. The two elements diverge from their attachments to the radius; the triangular fibrocartilage proper runs horizontally toward the styloid process of the ulna and the meniscus runs obliquely and downward into the triquetrum. *C,* Radiotriquetral band of the dorsal radiocarpal ligament.

The dorsal integument must be supple, elastic, and malleable. The skin of the back of the hand slides distally to allow metacarpophalangeal joint flexion. Interphalangeal flexion, as noted by Thomine (see Chapter 2), is accomplished by means of a special arrangement of skin folds on the dorsum of each articulation.

The vessels and nerves adapt themselves to differences in length and are surrounded by loose fibroadipose connective tissue.

The extrinsic muscles are elongated by the tendons, which, in order to perform their function, must glide in relation to the other elements of the hand. The gliding mechanism, which has an essential role, depends on various factors: the nature of the anatomic area through which it moves and the direction and amplitude of tendon movement. In the unrestricted areas where the tendon has a straight trajectory, it is surrounded by the paratenon, areolar connective tissue arranged in layers. This is the pattern for most of the extensor tendons except on the dorsal aspect of the wrist.

In narrow crowded areas, the gliding mechanism is assured by the synovial sheath, which allows a considerable amplitude of movement. The synovial sheaths at specific sites are surrounded by fibrous sheaths that keep the tendon close to the skeleton, in particular when the pulling tendons cross the sinus of an articular angle, as on the anterior and posterior aspects of the wrist or on the palmar aspect of the digital joints. The fibrous sheath assumes the role of a pulley when the tendon changes direction.

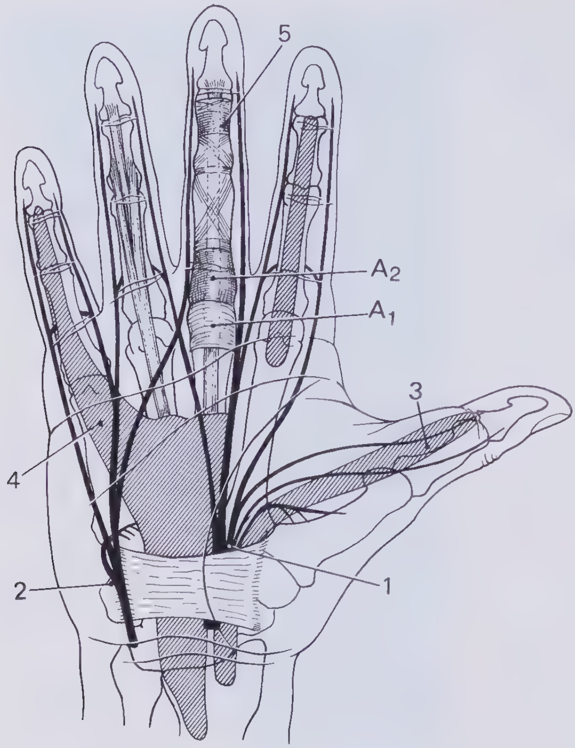


Figure 1–28. Diagram showing the different relations of the flexor tendons of the fingers at the wrist and in the hand. (*1*) The median and (*2*) ulnar nerves. The radial (*3*) and ulnar (*4*) synovial sheaths of the flexors extend as far back as the wrist. In the fibrous sheaths, note the important mechanical pulleys, including one opposite the metacarpophalangeal articulation inserting on the volar plate (A_1), another inserting on the first phalanx (A_2), and the pulley attached to the middle phalanx (A_4). (For details of the fibrous sheaths see Figure 1–5. For additional details relating to the pulley system, see Figure 1–50 on page 47.)

The gliding mechanism represented by the synovial sheaths is much more developed on the palmar aspect. There are three digitopalmar synovial sheaths for the flexor tendons of the index finger, long finger, and ring finger and two carpal digital sheaths for the flexor tendons of the thumb and little finger (Fig. 1–28). The superficial and deep flexor tendons of the digits also glide over each other.

On the dorsal aspect, the extensor synovial tendon sheaths are present only at the level of the wrist, which is the only joint in the hand capable of dorsal flexion. Each synovial sheath has a visceral and parietal component separated by a potential synovial cavity containing a very thin layer of synovial fluid, which constitutes the basic gliding and nutritional mechanism. Any alteration of these gliding mechanisms has important functional repercussions.

The Articular System

The skeleton of the hand has many articulations. No single articulation is an isolated mechanical entity in itself. The articulations of the hand form functional groups arranged in kinetic chains (Fig. 1–29).

A certain interdependence exists between the various articulations and the architectural structure of the wrist and hand. The position of each articulation depends on the equilibrium of forces acting at that level, and this equilibrium is subject to the position of the immediately proximal articulation. Thus what could be called a mobile balance is realized. The wrist influences the position of the metacarpophalageal joint; the metacarpophalangeal joint also affects the position of the proximal interphalangeal joint, which in turn affects the distal interphalangeal joint. The equilibrium and the interdependence between the

Figure 1–29. The architectural and functional harmony of the hand. In a normal hand the kinetic chains that make up the digits are not arranged at random. The phalanges and joints of the fingers are organized in regular curves—for the most part spirals—that give a spatial value to the functional equilibrium.

elements in the same osteoarticular chain are the result of several factors, both active and passive. The active factor is the dynamic balance between antagonist muscles (Duchenne, 1867), while the passive factors include the restraining action of ligaments (Landsmeer, 1955; Milford, 1968) and muscular "viscoelasticity," to use the term coined by Long and Brown (1964), which facilitates the coordination of motion. Single articular movements around a fixed perpendicular axis simply do not exist in the hand. Almost all the movements are around oblique and variable axes, resulting in combined movements permitting optimal orientation of the phalanges at the time of prehension.

The Muscles

One cannot consider the 17 mobile articulations of the digits and those of the wrist unrelated to the actions of the numerous muscles that act upon them. The muscles of the hand are customarily divided into two groups: the intrinsic and the extrinsic muscles. One may add a third group, namely, the muscles of the wrist. Both the origins and the insertions of the intrinsic muscles are in the hand, whereas the origins of the extrinsic muscles are in the arm and forearm and the insertions in the hand. This topographic distinction has only limited value functionally, however, because each movement is the result of many muscular actions.

Numerous muscles power the movements of the hand and wrist—20 extrinsic muscles (five muscles for the movements of pronation-supination, six for the movements of the wrist, and nine for flexion or extension of the digits) and 19 intrinsic muscles that permit the independent action of each phalanx. (The physical examination of each of these muscles is described in Chapter 3.) Over and above the details of their anatomical insertions, the examiner needs

to know the movement generated by each muscle, its stabilizing role in controlling an articulation, its force, and the excursion of its tendon. Knowledge of these motions is particularly valuable when one is planning to re-establish the action of a muscle or a group of muscles through a transfer.

The actions of the individual muscles of the hand were hard to interpret when we were limited to clinical or anatomical information. The development of electrical stimulation (Duchenne, 1867) and electromyography has brought a great degree of precision to the study of normal function. The muscles involved in free movement of the digits, power grip, and precision movements are not the same.

The power of a healthy muscle depends on the number of the muscle fibers and on their angle of insertion into the tendon. Muscular contraction becomes stronger as the number of fibers is increased and as the angle with its tendon diminishes (Zachary, 1946).

Evaluation of muscular force lacks precision. Since each movement involves several muscles, dynamic methods that used to be at our disposal were not sufficiently selective; electronic methods should allow a more precise evaluation.

Up to now, the method used to calculate muscular force has been that developed by Fick (1911) and Steindler (1940) in their anatomical studies. According to these authors, the force of a muscle is found by multiplying its surface area in cross section expressed in sq. cm. by a coefficient that is 10 kg. per sq. cm. with the Fick method and 3.65 kg. per sq. cm. with the Steindler method. The figures most often cited for the strengths of the extrinsic muscles of the hand are those of Lanz and Wachsmuth (1959), who themselves cite Fick (1911). Their values in kilogram-meters are given in Table 1–1 (Boyes, 1962).

The following figures have been calculated by Fahrer (1981) for the thenar muscles: abductor pollicis brevis, 0.50; opponens pollicis, 0.40; flexor pollicis brevis, 0.50; and adductor pollicis, 1.50. These figures are open to the following criticisms:

Table 1–1. STRENGTH VALUES OF THE EXTRINSIC MUSCLES OF THE HAND

Muscle	Strength (kg.-m.)
Brachioradialis	1.9
Pronator teres	1.2
Extensor carpi radialis brevis	1.1
Extensor carpi radialis longus	0.9
Extensor carpi ulnaris	1.1
Flexor carpi radialis	0.8
Flexor carpi ulnaris	2.0
Palmaris longus	0.1
Flexor pollicis longus	1.2
Extensor pollicis longus	0.1
Abductor pollicis longus	
As a wrist flexor	0.1
As a wrist abductor	0.4
Extensor pollicis brevis	0.1
Flexor digitorum superficialis	4.8
Flexor digitorum profundus communis	4.5
Extensor digitorum communis	1.7
Extensor indicis proprius	0.5

1. The value for the force of a muscle is obtained by multiplying the physiological surface area by a coefficient. The physiological surface is difficult to measure with precision because the muscle fibers are seldom parallel. As for the coefficient, its value is quite arbitrary.

2. The values are given in terms of working power, i.e., kg.-m. In mechanical terms, working power is defined as the force of a muscle, expressed in kilograms, multiplied by the distance of displacement of its insertion, expressed in meters. The displacement of the insertion is represented by the tendon excursion. Thus, a muscle developing a force of 50 kg. whose tendon moves 5 cm. will do the same work as a muscle developing a force of 100 kg. whose tendon moves only 2.5 cm. It would be more useful to have these evaluations in kilogram-force (kg.-f.) units or in newtons and not in kg.-m. (Fahrer and Pineau, 1976).

The values of the cross section as calculated by Fick are not absolute. Fahrer and Pineau (1976), for example, reported a mean value of 12 sq. cm. on one cadaver, compared to 21 sq. cm. given by Fick for the flexor digitorum superficialis.

The use of electronic transducers–strain gauge amplifiers allowed Ketchum et al. (1978) to compute the forces of the extensors of the wrist and later, by selective local anesthesia, the forces of the intrinsic muscles of the index finger and of the flexors and extensors of the fingers in normal hands. The combined forces of the intrinsic muscles of the index finger almost equal the combined forces of the long flexors.

Freehafer et al. (1979), using the same type of apparatus, directly measured the forces of muscle-tendon units about to be transferred in the forearm during surgery. The values obtained by these modern electronic techniques are of the same order of magnitude as the values computed by Fick in 1911. For example, the force of the extensor carpi radialis muscle has been estimated by Ketchum et al. (1978) to be 25.1 kg., by Freehafer et al. (1979) to be 17 kg.-m., and by Fick (1911) to be 31.4 kg.

At the level of the wrist the force of the flexors (2.9 kg.-m.) almost equals that of the wrist extensors (3.1 kg.-m.); whereas at the level of the digits, the force of the digital flexors (9.3 kg.-m.) greatly exceeds that of the extensors (2.5 kg.-m.). For the thumb, the muscular work performed by the intrinsic muscles exceeds that of the extrinsic muscles.

In the fingers the power of the intrinsic muscles is greater than the power of the long extensors (Ketchum et al., 1978). In the peripheral rays (i.e., the first and the fifth), the power of the intrinsic muscles is greater than that of the extrinsic muscles. By contrast, in the long and ring fingers, the extrinsic muscles are much more powerful than the intrinsic muscles. In the index finger the extrinsic muscles are only slightly more powerful, owing to the development of the first dorsal interosseous and first lumbrical muscles. This explains the important role of the intrinsic muscles in prehension and the severe loss of power when they are paralyzed.

The amplitude of gliding of a tendon depends especially on muscular contraction. The amplitude of contraction of a muscle reflects the potential that a muscle has of shortening itself as its fibers retract. The amplitude of contraction of a muscle is about one-third the length of its resting fleshy belly. It also is a function of the direction of its fibers. The amplitude increases if the fibers are longer and if the angle they make with the tendon is acute (Zachary, 1946).

The amplitude of tendon excursion is also controlled by other factors, such

as the adherence of muscle to its aponeurosis, the freedom of gliding of the tendon with its paratenon, the changes in the direction around a pulley, and the crossing of one or more articulations. Also the amplitude of gliding of the tendons of the extrinsic muscles of the hand varies in the same tendon, depending on its physical and metabolic integrity and on the level at which it is measured. Thus, the extensor digitorum has an amplitude of approximately 4 mm. at the distal interphalangeal joint, 8 mm. at the proximal interphalangeal joint, 15 mm. at the metacarpophalangeal joint, and 45 mm. at the wrist. The flexor tendons of the fingers have a much larger excursion. According to Verdan (1976), the amplitude of gliding is 5 mm. for the profundus at the distal interphalangeal joint, 16 mm. for the superficialis and 17 mm. for the profundus at the proximal interphalangeal joint, 26 mm. for the superficialis and 23 mm. for the profundus at the metacarpophalangeal joint, 46 mm. for the superficialis and 38 mm. for the profundus at the carpal canal, and 88 mm. for the superficialis and 85 mm. for the profundus in the distal forearm. These values are slightly greater than those noted by Boyes (1970). Large variations certainly exist from person to person.

According to Bunnell and Boyes, the maximal excursion for each tendon in the adult is as shown in Table 1–2 (Boyes, 1970).

Note that the motor muscles of the wrist have a tendinous excursion of approximately 3.5 cm. The common extensor of the fingers and the long flexor of the thumb have an excursion of approximately 4 to 5 cm., and the tendons of the long flexors of the fingers have the greatest excursion of all the muscles in the hand.

All the notions of topographical relationships of the muscles, their relative strengths, and their tendinous excursions are insufficient for the appreciation of the movements. The muscles are not controlled individually. "Movements, not muscles, are represented in the cerebral cortex"(Wood-Jones, 1942).

No muscle works alone, and the simplest action always requires the participation of antagonists. Movements are determined by the modulation of their respective forces. This is the important concept of "synergistic antagonism," which states that all movements are merely the result of a "displacement of dynamic equilibrium" between two or more muscles or groups of muscles (Kapandji, 1963).

Table 1–2. MAXIMAL EXCURSION OF THE TENDONS IN THE ADULT HAND

Tendon	**Maximal Excursion (cm.)**
Pronator teres	5.0
Extensor carpi radialis brevis	3.7
Extensor carpi radialis longus	3.7
Flexor carpi radialis	4.0
Flexor carpi ulnaris	3.3
Flexor pollicis longus	5.0
Extensor pollicis brevis	2.8
Abductor pollicis longus	2.8
Flexor digitorum profundus	7.0
Flexor digitorum superficialis	6.4
Extensor digitorum	4.5

MOVEMENTS OF THE FUNCTIONAL UNITS

The movements of the hand may be schematically divided into movements of the wrist, movements of the fingers, and movements of the thumb.

Movements of the Wrist

"The wrist is the key joint of the hand" (Bunnell). The study of the wrist and the forearm is inseparable from that of the hand. From the elbow distally, there is but a single physiological unit. For example, in pronation-supination the movement of the radius in relation to the ulna is in fact the movement of the hand around its longitudinal axis.

Wrist movements occur around three principal functional axes: longitudinal, transverse, and anteroposterior. Yet all these movements are complex and are not restricted to a fixed geometric axis.

Pronation-Supination: The Movement of Longitudinal Rotation. The radius does not revolve around a fixed axis of the distal ulna in this movement. In fact, the distal ulna itself moves in a small circle, within the arc of the radius, opposite in direction and situated in a more posterior plane (Capener, 1956; Vallois, 1926). In effect, the real axis of the hand and forearm for this motion is situated in the center of the distal radius, although it may be anywhere between the radial and ulnar styloid according to each respective arc (Fig. 1–30). Thus there is not one but many pronation-supinations.

Movement of the Hand on the Forearm. Movement of the hand on the forearm brings into play the two series of articulations of the wrist—the radiocarpal and the midcarpal. These articulations allow motion into two axes—anteroposterior in flexion-extension and transverse in lateral deviation. These movements are complicated by the morphology of the wrist, which is a zone of architectural transition between the two bones of the forearm and the five

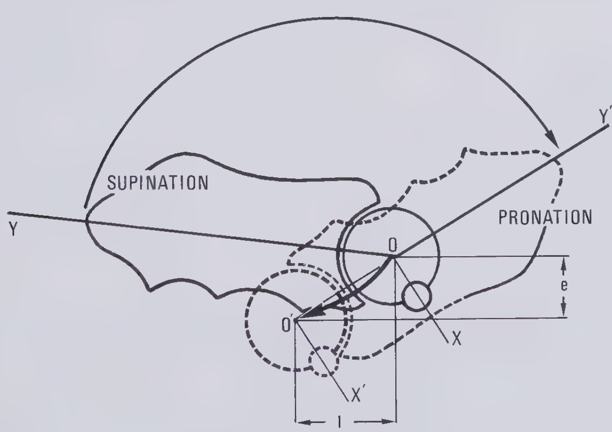


Figure 1–30. Pronation-supination at the wrist level. Pronation-supination is a complex movement that mobilizes the lower end of the radius and ulna. The radius undergoes a rotation of almost 180 degrees, and the ulna undergoes a movement on the arc of a circle. The center of these two movements has no fixed location. It is located somewhere in the distal end of the ulna, but the axis of pronation-supination is variable, not only from movement to movement but also during the course of the same movement. (After Kapandji, I. A.: Physiologie Articulaire. Paris, Librairie Maloine, 1963, Vol. 1.)

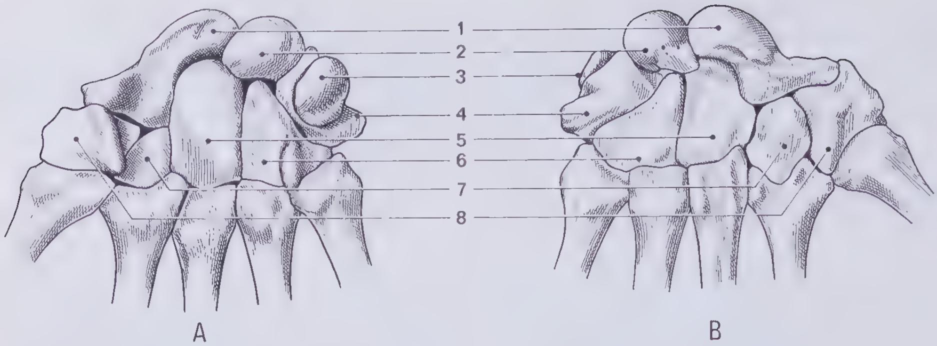


Figure 1–31. The carpal bones. *A,* Palmar view. *B,* Dorsal view. 1, Scaphoid. 2, Lunate. 3, Pisiform. 4, Triquetrum. 5, Capitate. 6, Hamate. 7, Trapezoid. 8, Trapezium.

metacarpals forming the palmar concavity necessary to facilitate opposition of the thumb. The anterior concavity of the wrist also plays an important role in balancing the forces of the long tendons in the synergistic action of the finger flexors and the extensors of the wrist (see Fig. 1–12).

The eight bones of the carpus are schematically arranged into a proximal row and a distal row, although the scaphoid straddles the lunate-capitate interspace, articulating with both the trapezoid and the trapezium (Fig. 1–31). Destot (1923) likened the distal aspect of the two bones of the forearm with their triangular ligament to a third carpal row. He described the scapholunate as a "mobile and supple meniscus," since the articulations of its component bones are united by the interosseous ligaments. These permit the bones to arrange themselves according to wrist movements.

Extensive carpal mobility would be impossible without scapholunate action, as was first described by Henke (1859). Later Fick (1901, 1911) described the mutual displacement of the ossicles as indispensable in allowing the proximal row to articulate with the distal row. He offered the hypothesis that the scaphoid always maintains contact with the trapezium by flexing and pivoting. According to Destot, "the scapholunate joint appears essential" not only for the physiology of the wrist, but also because "all the traumatic pathology of the wrist concentrates in the lesions of these ossicles." This is now accepted as being only partially true.

The bones of the proximal row do not form a simple articular surface opposed to the articular surface of the forearm bones and moving around two well defined axes. The motion of each of its ossicles should be studied individually. Landsmeer (1968, 1976) and his school, and Kauer (1964) among others, have compared the mechanism of the carpus to that of longitudinal parallel chains (Fig. 1–32):

1. An external chain is composed of the radius, scaphoid, and trapezium prolonged by the column of the thumb.

2. A middle chain is formed by the radius, lunate, capitate, and the third metacarpal. The lunate tilts slightly toward the ulnar side so that one-third of its proximal articular surface lies in contact with the triangular ligament. These two chains are connected by the scapholunate ligament whose fibers of unequal length allow the mutual displacement of the two ossicles, and by the capitate, which articulates with the scapoid and the lunate through two distinct articular facets. In a sense, then, the scaphoid and the lunate are "intercalary" bones.

3. Finally, the medial chain formed by the triquetrum and the hamate

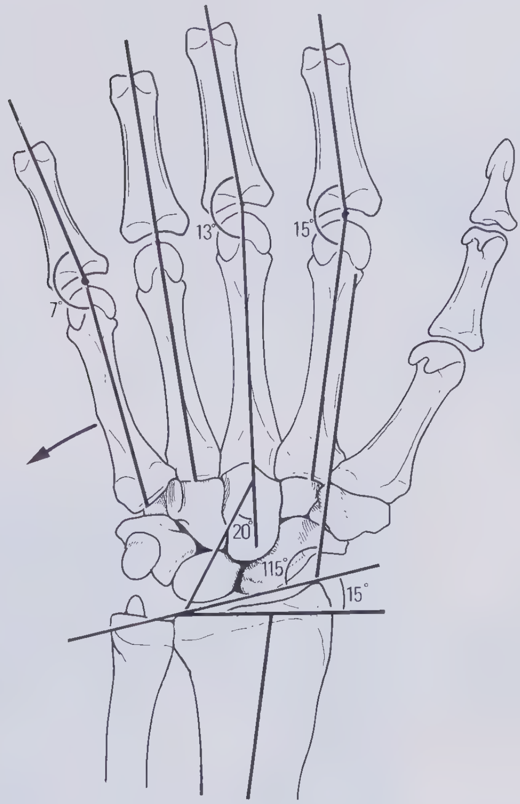


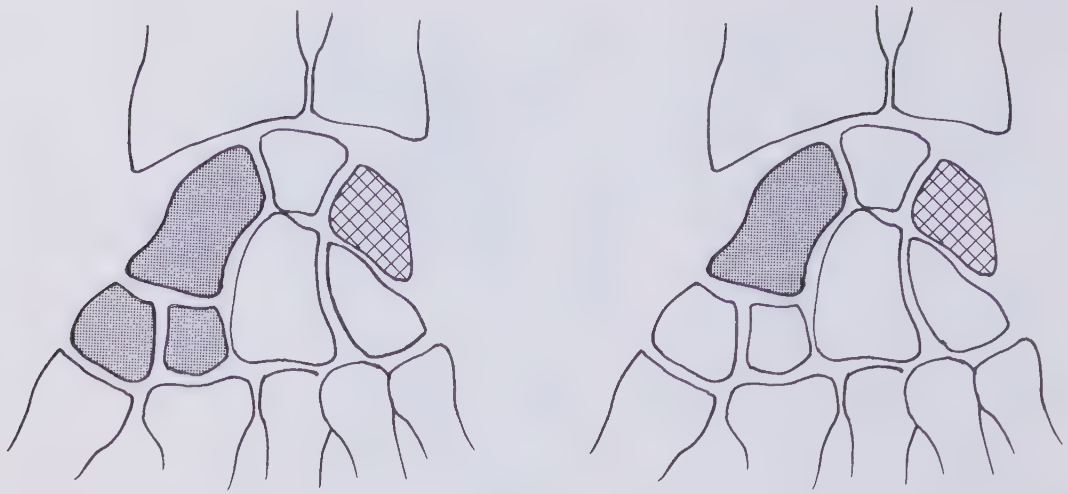
Figure 1–32. The physiological angles between the different skeletal structures of the hand. The articular surface of the distal end of the radius is directed ulnarly at an angle of approximately 15 degrees. The axis of the lunate forms an angle of approximately 20 degrees with a straight line passing through the capitate and third metacarpal. The axis of the second metacarpal is in line with the longitudinal axis of the radius. The longitudinal axis of the proximal phalanges is inclined ulnarly to the metacarpal axis approximately 15 degrees for the index finger, 13 degrees for the middle finger, and 7 degrees for the fifth finger. Only the first phalanx of the ring finger is in line with the axis of its metacarpal. The angle between the radial border of the second metacarpal and the lower border of the distal end of the radius is 115 degrees (Schapiro, 1970).

constitutes the axis of pronosupination. It has been called the column of rotation (Taleisnik, 1976).

Taleisnik points out that the distal row of the carpus can be regarded as a single anatomical and functional unit that, with the lunate, makes up the central column of flexion-extension. This leaves the scaphoid as the only mobile part of the lateral column and the triquetrum as the only part of the medial column (Fig. 1–33).

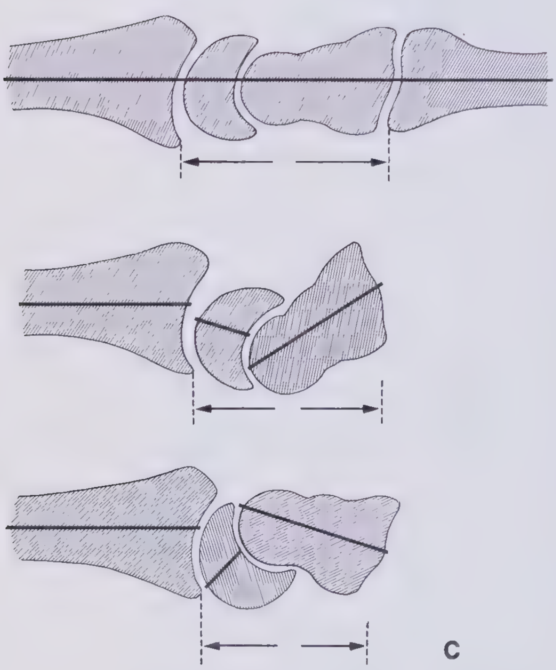
The assimilation of the carpal bones into chains of longitudinal bones permits an explanation of opposite displacements after certain traumatic lesions or in rheumatoid synovitis of the capsuloligamentous apparatus (Fig. 1–33).

Frontal Lateral Movements. It must be noted that there is a physiological ulnar deviation at rest, easily demonstrated clinically and radiologically. The collateral movements of the wrist have an ulnar amplitude of approximately 40 degrees and a radial amplitude not greater than 15 degrees (Fig. 1–34). The muscle with the best momentum for adduction of the wrist in pronation is the extensor carpi ulnaris; the abductor pollicis longus and extensor pollicis brevis have the best momentum for abduction of the wrist. This motion occurs at the radiocarpal articulation as well as at the midcarpal level, but in different proportions: Fifty-five to 60 per cent occurs at the radiocarpal joint in ulnar deviation and 60 to 65 per cent occurs at the midcarpal joint in radial deviation (Kaplan, 1975), but individual variations are considerable. The axis of these movements runs through the capitate (Santos-Gutierez, 1964). However, these movements are not simple inclinations in abduction and adduction. Extension of the wrist facilitates radial deviation, and flexion of the wrist facilitates ulnar deviation.



A

B



C

Figure 1–33. The columnar or vertical carpus. The carpal bones are grouped into three vertical columns. *A,* According to Navarro (1937), the lateral or mobile column is composed of the scaphoid, trapezium, and trapezoid; the central or flexion-extension column is formed by the lunate, capitate, and hamate; and the medial or rotation column is composed of the triquetrum. *B,* A modification of this concept (Taleisnik, 1976). The central column is expanded to include the lunate and all four of the distal bones, reducing the lateral column to the scaphoid. The central column forms with the radius a longitudinal three segment link. Each column is a functional unit. This concept helps in understanding the physiology and pathology of the wrist. It has practical applications in the treatment of instability of the wrist and avascular necrosis of the carpolunate joint. *C,* The lunate and the capitate are intercalary bones between the radius and the third metacarpal. In pathological situations these bones undergo displacement in flexion or extension, according to the location of ligamentous changes. Schematically, in the course of rheumatoid arthritis, the lunate rocks into flexion, whereas in traumatic ligamentous conditions, it levers into extension (Linscheid and Dobyns, 1971). The tilt of the carpus is accompanied by a shortening of the distance between the radius and the metacarpals (shortening of the carpus).

Anteroposterior Movements. The anteroposterior movements of flexion and extension of the wrist have a range of approximately 80 degrees in each direction, distributed among the radiocarpal articulation and the intercarpal articulation in proportions that vary among different studies (Fick, 1911; MacConaill, 1941). These are not simple displacements in flexion or in extension; rotation and a rocking motion are present simultaneously.

Kuhlmann et al. (1978a) point out that, owing to the particular shape of the scaphoid and the lunate, the distance between the lower end of the radius and the distal row of the carpus will vary according to the position of the wrist. For example, it is greater in flexion than in extension.

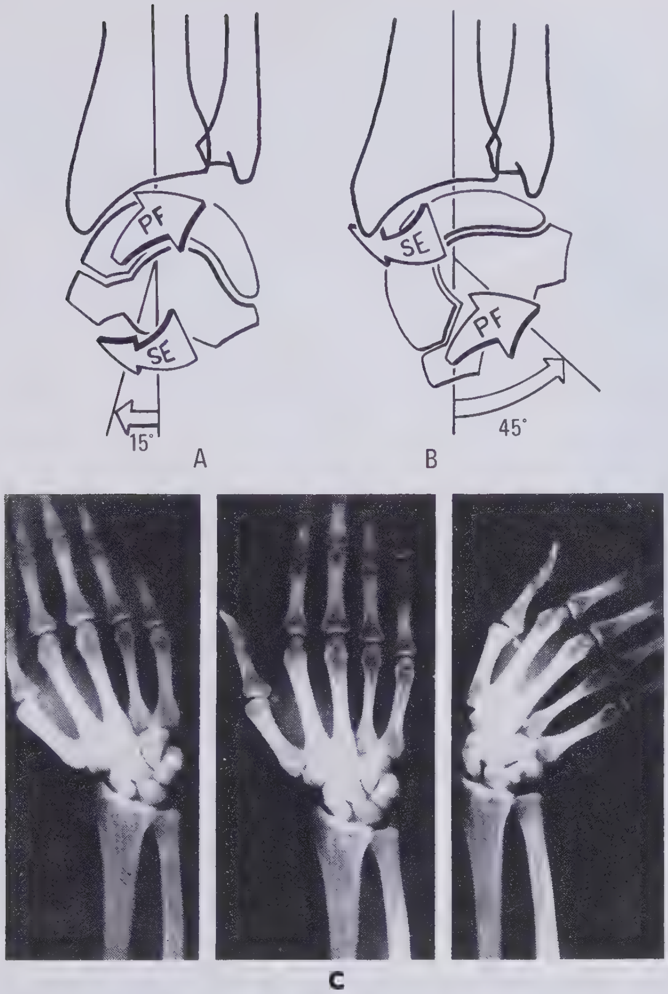


Figure 1–34. Lateral movements of the wrist. Abduction (radial inclination) and adduction (ulnar inclination) of the wrist consist of movements occurring at the radiocarpal joint and midcarpal joints. *A,* During abduction, the proximal row also executes a pronation-flexion (PF) and the distal row a supination-extension movement (SE). *B,* During adduction, the movements are in reverse: supination-extension (SE) for the proximal row and pronation-flexion (PF) for the distal row. In both instances these accessory movements cancel each other out. Note that the ulnar inclination is three times the radial inclination. *C,* X-ray views showing complete radial and ulnar inclination. (*B* after Kapandji, A. I.: Physiologie Articulaire. Paris, Librairie Maloine, 1963, Vol. 1.)

Taleisnik (1976) has pointed out that during dorsiflexion and ulnar deviation the scaphoid becomes longitudinal, the carpus behaves as a single unit, and the wrist motion is predominantly radiocarpal. Conversely, in volar flexion and radial deviation, when the scaphoid position is perpendicular to the long axis of the radius, the midcarpal joint is "unlocked." Volar flexion and radial deviation are mainly midcarpal joint motions.

The motion of wrist extension is accompanied by a slight radial deviation and pronation of the forearm. Inversely, the movement of flexion is accompanied by a slight ulnar deviation and supination of the forearm and a synergistic contraction of the biceps, which in effect at the same time limits extension of the elbow (Capener, 1956). Moreover, the position of the wrist in flexion or

Figure 1–35. The flexor muscles of the wrist. From radial to ulnar: flexor carpi radialis, palmaris longus, and flexor carpi ulnaris.

extension influences the tension of the long or "extrinsic" muscles of the digits, which are "polyarticular" and traverse the wrist and finger joints.

The wrist is stabilized by its extrinsic muscles, incorrectly termed "monoarticular." In reality, all the "proper" muscles of the wrist insert beyond the carpus, which constitutes an intercalary system, including the slender and inconstant palmaris longus, whose lateral tendon continues to the base of the proximal phalanx of the thumb (Fahrer and Tubiana, 1976), and the powerful flexor carpi ulnaris, which inserts beyond the pisiform into the fibers continuing with the abductor digiti quinti, thus forming a digastric system (Fahrer, 1975). These "proper" muscles are divided into two groups: three flexor muscles and three antagonistic extensor muscles (Figs. 1–35, 1–36). The extensor carpi radialis brevis inserts on the base of the third metacarpal, and its midposition gives it an essential role in wrist extension. The extensor carpi radialis longus extends the wrist with radial deviation. The extensor carpi ulnaris tendon extends the wrist with a strong ulnar deviation.

This action needs some explanation. The extensor carpi ulnaris tendon has a specific fibrous tunnel formed by the deep layer of the antebrachial fascia, which allows some transverse mobility. It lies on the medial aspect of the ulnar head in pronation and moves more centrally toward the radius in supination. Therefore, in supination this muscle extends the wrist synergistically with the extensors carpi radialis longus and brevis, whereas in pronation it becomes their antagonist and works in synergy with the flexor carpi ulnaris. In a normal

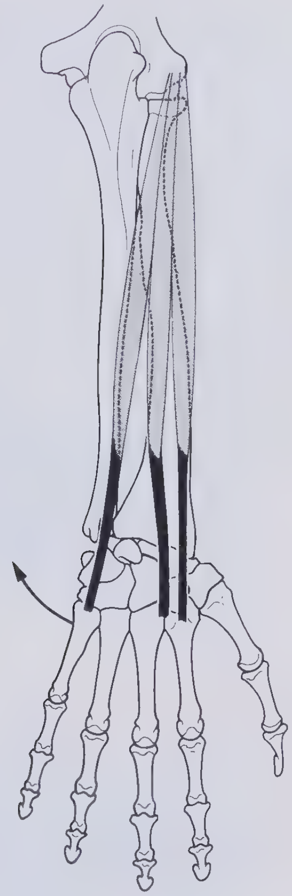


Figure 1–36. The extensor muscles of the wrist. From radial to ulnar: extensor carpi radialis longus, extensor carpi radialis brevis, and extensor carpi ulnaris. All these muscles are inserted distal to the carpus.

wrist, the extensor carpi ulnaris plays an important role by stabilizing the wrist and preventing radial deviation during pronation (Fig. 1–37).

Neither the flexors nor the extensors of the fingers are long enough to allow maximal movements at the wrist and the fingers simultaneously. The restraining action of the long antagonistic muscles explains why complete flexion of the fingers is possible only if the wrist is in slight extension of about 20 degrees (Fig. 1–38). This is the optimal position for hand function. Conversely, flexion of the wrist puts some tension on the long extensors, resulting in an automatic opening of the fingers.

When the wrist is flexed, the pulp of the thumb reaches the level of the proximal interphalangeal joint of the index finger; when it is in extension, the pulps of the thumb and index finger are passively in contact (Fig. 1–39). Thus the position of the wrist has important repercussions on the position of the thumb and fingers. This explains why the movements of the wrist, usually in reverse of the movements of the fingers, reinforce the action of the extrinsic muscles of the fingers. Thus the wrist extensors are synergistic with the more powerful digital flexors. The combined movements are facilitated by the architecture of the wrist. The digital flexor tendons cross the wrist within the depths of the carpal arch and are held close to the axis of flexion-extension of the wrist. Thus the movement arm in the direction of wrist flexion is minimized, which allows the wrist extension necessary for full digital flexion (see Fig. 1–12). As the wrist position changes, the functional lengths of the digital flexor

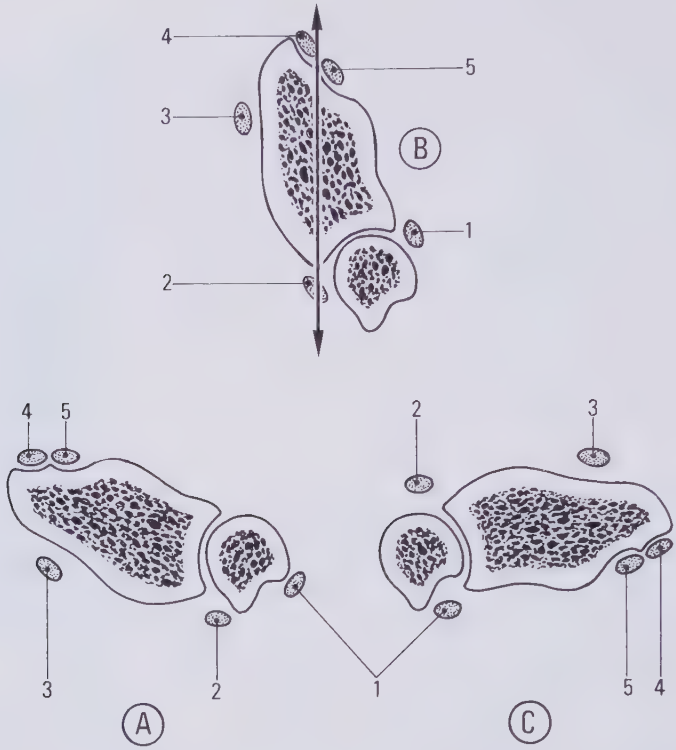


Figure 1–37. Position of the tendons of the flexors and extensors of the wrist during pronation and supination. 1, Extensor carpi ulnaris. 2, Flexor carpi ulnaris. 3, Flexor carpi radialis. 4, Extensor carpi radialis longus. 5, Extensor carpi radialis brevis. *A,* In pronation the extensor carpi radialis longus and brevis are extensors of the wrist, and the flexor carpi ulnaris is a flexor of the wrist. The flexor carpi radialis and extensor carpi ulnaris are lateral stabilizers. *B,* In the neutral position the axis of movements of the wrist is oblique. This axis is between the extensor carpi radialis and the flexor carpi ulnaris. *C,* In supination both the extensores carpi radiales and the extensor carpi ulnaris act as extensors of the wrist. The flexor carpi radialis and ulnaris are flexors. The changes in position of the ulna, which are less important than those of the radius, are not shown in these diagrams for the sake of clarity. (*A* after Stack, G. H. and Vaughan-Jackson, O. J.: The zig-zag deformity in the rheumatoid hand. Hand, *3*:62–67, 1971. *B* after Capener, N.: The hand in surgery. J. Bone Joint Surg., *38B*:128, 1956.)

tendons change and the resultant forces in finger flexion vary. In order for grip to be effective and have maximal force, the wrist must be stable (paralysis of the "proper" wrist muscles, the flexors or extensors, considerably diminishes the force of the digits) and the wrist must be in slight extension and ulnar deviation. In full flexion of the wrist, the grip strength of the hand is 25 per cent of its maximum in extension (Napier, 1966).

Studies done with the digital dynamometer and Beckman dynograph recorder have allowed evaluation of the influence of wrist position on the force generated at the middle and distal phalanges (Hazelton et al., 1975). The wrist position in which the greatest force is exerted is ulnar deviation and then extension; the least force is generated in volar flexion.

We have stressed the influence of wrist position on the more distal joints in the normal hand. In disease, the position of the wrist also influences the more distal joints. Thus, lateral deviation of the wrist can involve an opposite deviation of the metacarpophalangeal joint when the stabilizing elements of these joints (lateral ligament and volar plate) are weakened. For example, destruction or distention of the ligaments of the wrist result in ulnar deviation

A

B

Figure 1–38. Role of the wrist in positioning of the digits. *A,* Extension of the wrist permits full flexion of the digits. The synergistic action of the extensors and flexors of the wrist is made possible by the shape of the transverse carpal arch, which allows the flexor tendons to be kept close to the axis of flexion-extension of the wrist. If the flexor tendons were displaced volarly, for example by synovitis of the wrist, extension would be reduced and full finger flexion would be impossible. *B,* Conversely, wrist flexion places the long extensors under tension and automatically extends the digits.

of the carpus and radial deviation of the carpometacarpal block: the carpus slides medially on the curve of the distal end of the radius.

The proliferation of rheumatoid synovitis displaces forward the tendon of the extensor carpi ulnaris, and the predominant action of the radial tendons (i.e., the flexor carpi radialis and the extensors carpi radialis longus and brevis)

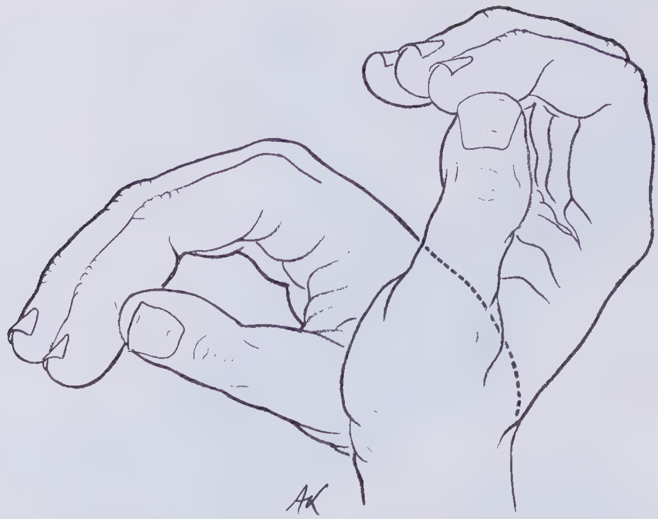


Figure 1–39. When the wrist is flexed, the tip of the thumb is level with the distal interphalangeal joint of the index finger. In wrist extension the pulps of the index finger and thumb come passively into contact.

deviates the carpometacarpal block radially. This inclination increases the angle between the radial border of the second metacarpal and the lower border of the distal radius, which is normally 115 degrees (Shapiro, 1970; Fig. 1–40). In the functional aspect, the radial inclination of the hand induces an important loss of muscular power in the flexors (Hazelton et al., 1975).

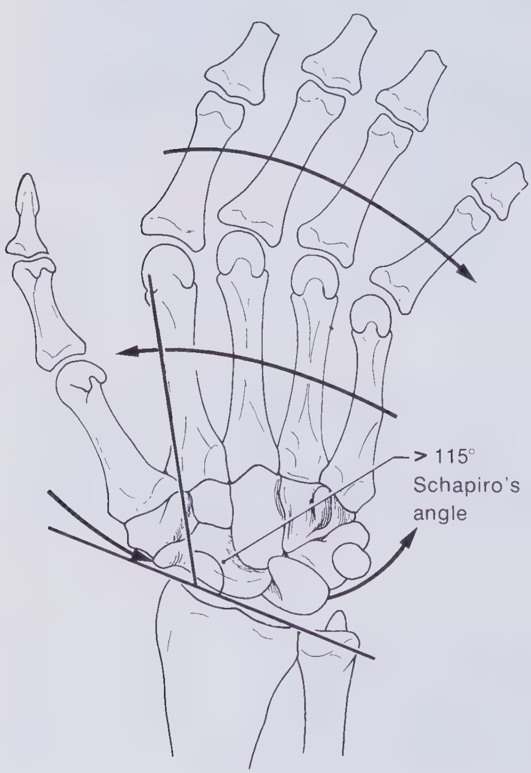


Figure 1–40. Skeletal deformity in rheumatoid arthritis. The carpometacarpal block inclines radially (outward). Schapiro's angle is more than 115 degrees. The proximal phalanges may incline ulnarly, thus greatly increasing the digital deformity.

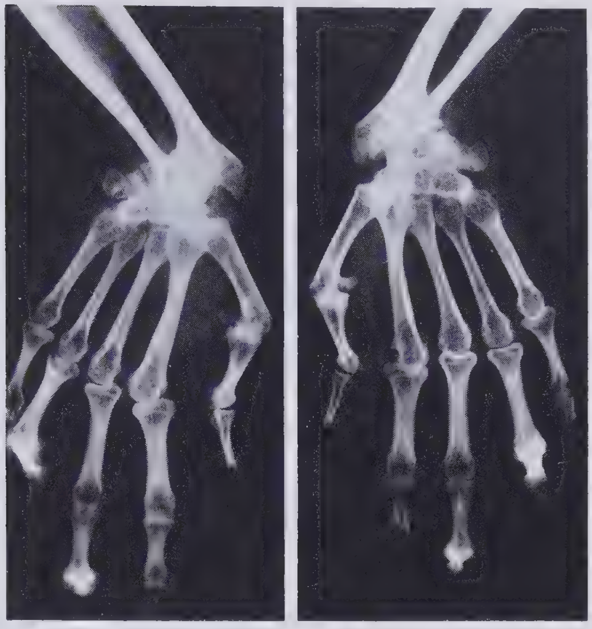


Figure 1–41. Ulnar deviation of the carpometacarpal block in juvenile rheumatoid arthritis. The index and middle fingers of each hand are in radial deviation.

The radial deviation of the carpometacarpal block may produce ulnar deviation of the metacarpophalangeal joints because of the interdependence of various articulations in the longitudinal chains (Pahle and Raunio, 1969; Stack and Vaughan-Jackson, 1971). The opposite deviation of the carpometacarpal block, which is seen in juvenile rheumatoid arthritis, may be associated with radial deviation of the digits (Fig. 1–41).

Clinically, however, ulnar drift of the metacarpophalangeal articulations often precedes the wrist deformities. This simply means that factors other than deviation of the wrist may be influencing the deviation of the digits.

These concepts of the position of the joints in regard to muscle equilibrium are particularly complex at the digital level (Tubiana and Hakstian, 1969).

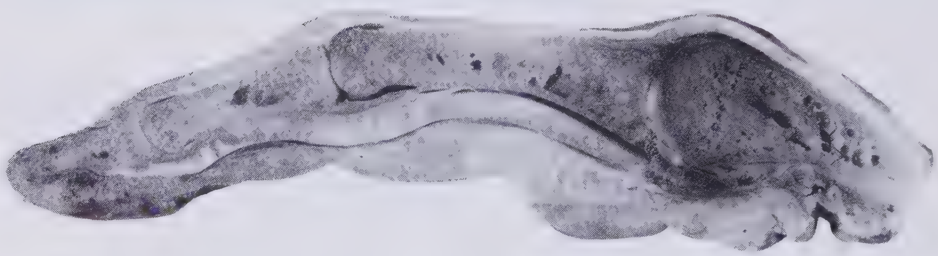
Movements of the Fingers

Articulations of the Fingers

The articulations of the fingers form a triarticular chain that flexes toward the thumb and the palm to allow grasp. This disposition of the fingers in a polyarticular chain permits all varieties of grip, from a simple pinch to wrapping around an object. The encompassing movement of the phalanges in going from extension to full flexion becomes an "equiangular spiral," as has been noted by Littler (1973), corresponding to the numerical sequence 0, 1, 1, 2, 3, 5, 8, 13, 21 . . . discovered by Fibonacci in 1202. It is the natural biological spiral in snails, shells, and flowers, to mention a few (Fig. 1–42).

The articulations of the digits have one common, essential feature: they function in the direction of flexion and have two firm collateral ligaments and a thick reinforced anterior capsule, the anterior fibrocartilage, also known as the volar plate. By contrast, the fibrous dorsal capsule is thin and lax (Fig. 1–43).

Figure 1–42. The series of Fibonacci and the biological spirals. Fibonacci in 1202 studied the properties of the numerical series 0, 1, 1, 2, 3, 5, 8, 13, 21, . . . (each number is equal to the sum of the two preceding numbers), which corresponds to an "equiangular spiral." Since then biologists have recognized that this typical progressive spiral corresponds to all the spirals seen in flowers and seashells. Littler (1973) has noted that the length of the metacarpal and the phalanges of the same finger resembles the series of Fibonacci; as a matter of fact, in complex flexion a finger describes an equiangular spiral.



A

B

Figure 1–43. Sagittal section of a finger in flexion and extension, demonstrating the osseous chain and the planes of articular and tendinous movements. The volar tendinous apparatus, consisting of the two flexor tendons, is considerably stronger than the dorsal extensor apparatus. Also the capsular structures and the fibrofatty cushions are much stronger, and even the skin is thicker on the flexor side. The finger is designed to function in flexion.

There are notable differences between the interphalangeal and metacarpophalangeal articulations of the digits and even between the articulations at the same level for each digit (Hakstian and Tubiana, 1967; Kuczynski, 1968; Landsmeer, 1955; Smith and Kaplan, 1967). These differences are produced by the shape of the articulations, the orientation of the articular surface, the synovial insertion, the disposition of the collateral ligaments, and the degree of play in the volar plate, as well as by the more superficial tissues that encircle them and play an uncertain role in their stability. These elements condition the mobility and stability of these articulations and the orientation of the distal segments. As the thumb pulp pronates in opposition, the pulps of the fingers supinate in external rotation, when the metacarpophalangeal joints flex or when the index finger moves radially. These variations in orientation allow for optimal use of the finger pulps (Fig. 1–44).

The range of movements of the individual joints of the fingers varies. Flexion of the metacarpophalangeal joint is about 85 degrees, the proximal interphalangeal joint about 115 degrees, and the distal interphalangeal joint 80 degrees. There is also a difference in the range of movements between the thick fingers of the manual worker and the fingers of the nonmanual worker. Each finger also has a slightly different range of movements. For example, the index finger is capable of less flexion than the others because it opposes the thumb.

Interphalangeal Articulations. The interphalangeal articulations of the digits function uniquely in the flexion-extension sense, and their trochlear shaped articulations are closely congruent throughout excursion of the joint. These interphalangeal articulations must have good lateral stability in every position, achieved by two strong symmetrical collateral ligaments inserting on the axis of rotation of the two epiphyseal regions of the phalanges.

Proximal Interphalangeal Joint. The proximal interphalangeal joint must be stable in all positions. This is achieved by three main structures:

1. Two strong symmetrical collateral ligaments arise on the proximal phalanx near the axis of rotation of the joint and insert obliquely into the base of the distal phalanx. These are supported by collateral accessory ligaments whose origin is similar, but they insert volarly into the volar plate.

2. The volar plate, which prevents hyperextension, has a thick distal insertion and two check ligaments proximally inserted on the middle phalanx. It is interesting that traumatic ruptures of the volar plate usually occur in the thicker distal insertion rather than in the thinner proximal insertion.

3. The fibrous flexor sheath is inserted on the volar plate and on the base of the phalanx immediately proximally and distally. This differs from the insertion at the metacarpophalangeal joint, where the fibrous flexor sheath inserts on the volar plate and on the base of the proximal phalanx but not on the metacarpal.

This arrangement involving the collateral ligaments, volar plate, and flexor sheath forms a three dimensional junction and is the key to interphalangeal stability. If the corners of this junction remain intact, significant interphalangeal joint displacement is impossible (Eaton, 1971).

Distal Interphalangeal Joint. The distal interphalangeal joint has similar structures but less stability and allows some hyperextension, giving a larger pulp contact.

Metacarpophalangeal Joints. The metacarpophalangeal joints allow flexion-extension and medial-lateral deviation associated with a slight degree of axial rotation; hence, their capsules are much looser than those of the interphalangeal

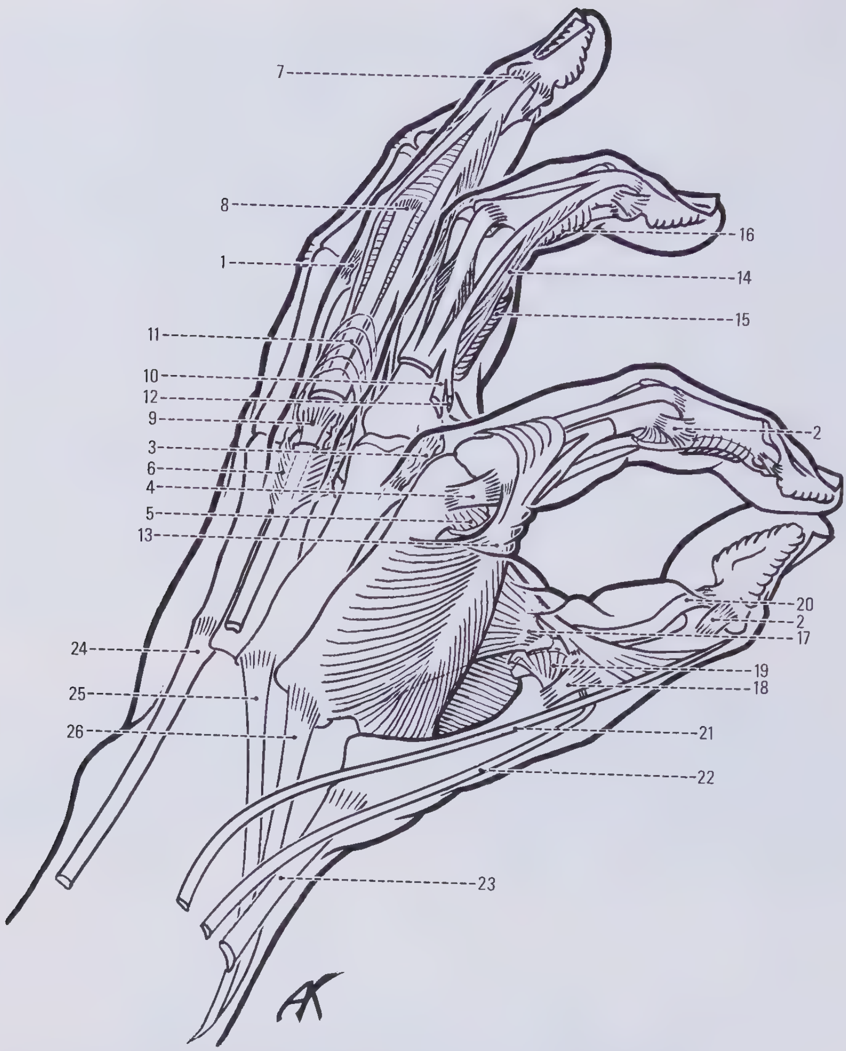


Figure 1–44. The hand with the skin removed (Kapandji). 1, Collateral ligament of the proximal interphalangeal joint slightly relaxed in complete extension and (2) tightened in intermediate flexion. 3, Collateral ligament of the metacarpophalangeal joint relaxed in extension and (4) tightened in flexion. 5, Accessory fibers of the collateral ligament of the metacarpophalangeal joint inserting on the volar plate. 6, Expansion of the common extensor on the interglenoid (deep intermetacarpal) ligament. 7, Distal insertion of the extensor digitorum on the distal phalanx. 8, Insertion of the middle extensor tendon on the middle phalanx. 9, Deep expansion on the proximal phalanx. 10, Expansion of the interosseous to the lateral band of the extensor digitorum. 11, Interosseous hood. 12, Lumbrical tendon. 13, First dorsal interosseous with its complete system of insertion and the tendon of the first lumbrical. 14, Retinacular ligament. 15, Flexor pulley on the first phalanx. 16, Distal pulley on the second phalanx. 17, Adductor pollicis with its insertions on the internal sesamoid, the base of the proximal phalanx, and the dorsal aponeurosis. 18, Medial collateral ligament of the metacarpophalangeal joint of the thumb. 19, Accessory collateral ligaments inserted into the volar plate and the sesamoid. 20, Flexor pollicis longus. 21, Extensor pollicis longus. 22, Extensor pollicis brevis. 23, Abductor pollicis longus. 24, Extensor carpi ulnaris. 25, Extensor carpi radialis brevis. 26, Extensor carpi radialis longus.

articulations. The metacarpal condyle, which has a larger anteroposterior axis, articulates with the base of the proximal phalanx, which is smaller and concave and has a larger transverse axis. The surface of the glenoid cavity is amplified by the volar plate and can thus accommodate the metacarpal head. This arrangement allows great amplitude of movement, at the expense of stability, which is provided by the capsuloligamentous apparatus (Flatt and Fischer,

1969). The lax capsule is considerably reinforced by the radial and ulnar metacarpophalangeal ligaments. These are relaxed in extension and tensed in flexion because of their eccentric insertions and the shape of the metacarpal head (narrower posteriorly and more prominent anteriorly; Fig. 1–45). This explains why abduction-adduction movements of the metacarpophalangeal joints are restricted in flexion and free in extension. In contrast to the interphalangeal articulations, which are stable throughout most of their range of movements, the metacarpophalangeal joints are stable only in flexion. Their configuration also explains why the metacarpophalangeal joints never, under any circumstances, should be immobilized in extension or hyperextension, which would result in their locking by retraction of the collateral ligaments.

The lateral accessory metacarpoglenoid ligaments suspend the volar plate, to which is attached the first pulley of the fibrous sheath of the flexor tendons. Any malalignment at the entrance of the fibrous sheath will have important repercussions on the deviation of the digit.

The asymmetry of the metacarpal heads as well as the difference in length and direction of the collateral ligaments also explains why the ulnar inclination of the digits normally is greater than the radial inclination (Fig. 1–46).

Normal Ulnar Inclination of the Fingers. The normal ulnar inclination of the fingers occurs at the metacarpophalangeal joints. The inclination is most marked in the index finger, less in the middle and little fingers, and almost nonexistent in the ring finger (Fig. 1–32). It is due to a number of anatomical factors, which have been the subject of numerous studies in recent years as a result of the development of hand surgery for rheumatoid arthritis (Flatt, 1971). These factors have different consequences in different fingers:

1. Articular effects because of the asymmetry of the metacarpal heads and the collateral ligaments (Hakstian and Tubiana, 1967).

2. Effects on tendons. The extrinsic tendons, extensors and flexors, cross into the hand on the ulnar side of its longitudinal axis (Smith et al., 1964).

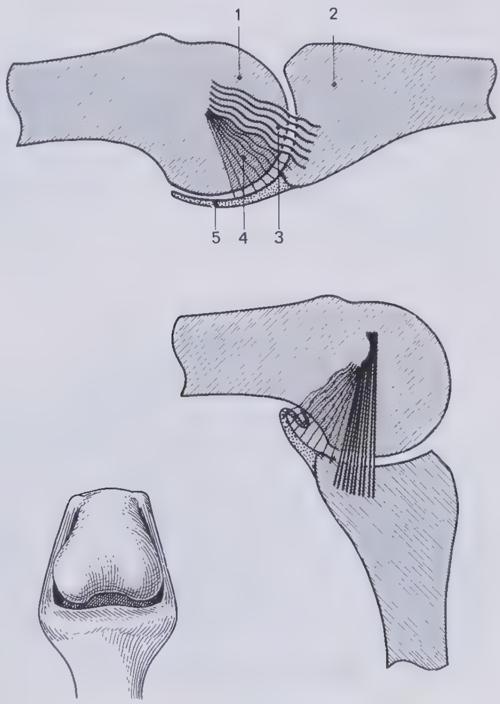


Figure 1–45. Because the metacarpal head is narrow dorsally and because of the projection of the condyle anteriorly, the collateral ligaments are tight in flexion and relaxed in extension. The most proximal fibers of the accessory collateral ligament, which is a proximal prolongation of the collateral ligament and is inserted onto the volar plate, are slack in full flexion. 1, Metacarpal head. 2, Proximal phalanx. 3, Collateral ligament. 4, Accessory collateral ligament. 5, Volar plate.

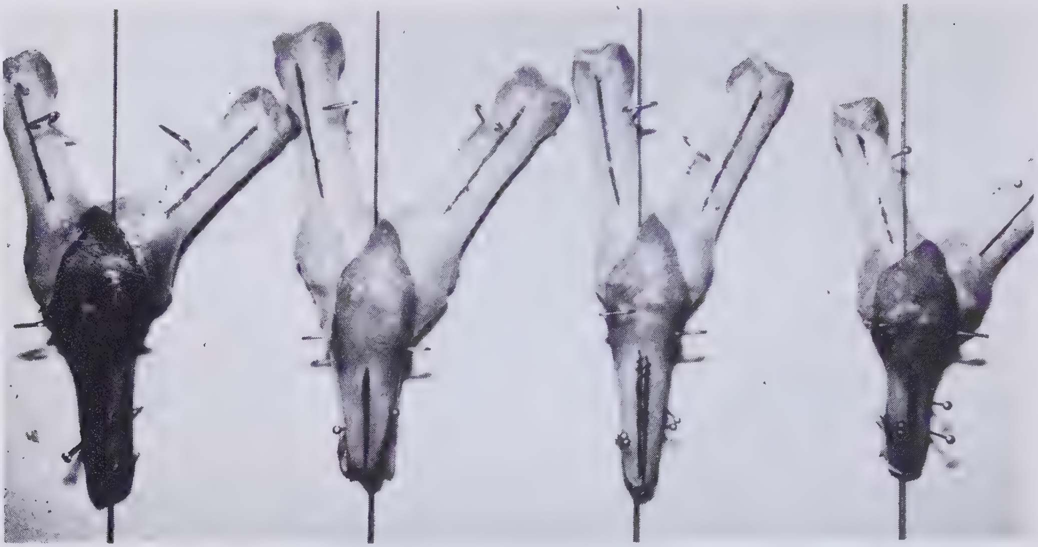


Figure 1–46. Anatomical preparation showing that at the level of all the metacarpophalangeal joints of the fingers, the ulnar deviation of the first phalanx is much more important than the radial deviation. The radial deviation is approximately 13 degrees for the index finger, 8 degrees for the middle finger, 14 degrees for the ring finger, and 19 degrees for the little finger. Ulnar deviations are 43, 34.5, 20, and 33 degrees, respectively (Hakstian and Tubiana, 1967).

3. Effects on muscles. The intrinsic muscles with a predominantly ulnar inclination predominate over those with a radial inclination, because their insertions are more distal and especially because of the force of the hypothenar muscles.

4. Zancolli (1979) has emphasized the role of the forward displacement of the two ulnar metacarpals (the "metacarpal descent"), which pull ulnarward the extensor tendons united by their intertendinous connections (juncturae tendinum; Fig. 1–47). To these anatomical factors we must add the physiological action of the thumb, which in lateral grip pushes the fingers ulnarward.

The ulnar inclination is normally limited by the capsuloligamentous resistance at the metacarpophalangeal joints and by the action of the interosseous muscles, which act in a radial direction. The weakness of these stabilizing elements (particularly in rheumatoid arthritis when the metacarpophalangeal joints are distended by proliferative synovium, or after capsulectomies of metacarpophalangeal joints in hands in which the intrinsic muscles are paralyzed) allows the ulnar inclination to be accentuated, resulting in pathological ulnar deviation.

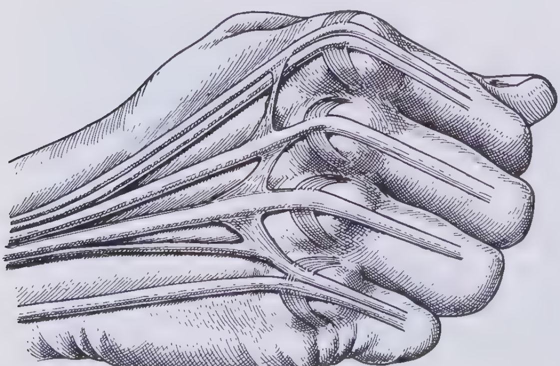


Figure 1–47. The common extensor tendons of the fingers are joined together at the distal part of the back of the hand by the conexus intertendineus. The tendon of the extensor digitorum for the little finger in the majority of cases leaves the common extensor of the ring finger distally, as shown in the diagram. During closure of the fingers, the fourth and fifth metacarpals flex forward, drawing the extensor tendons down and inward. (After Zancolli, 1979.)

Muscular Equilibrium at the Level of the Digits

Two forearm muscular "extrinsic" systems power the movements of opening and closing the digits (Fig. 1–48). The dominance of the flexor system, composed of two strong muscles inserting on the distal phalanges, accounts for the considerable force of the encircling polyarticular chain that ensures grip.

The Flexor Apparatus. The flexor tendons of the fingers cross five well defined regions, which are, from proximal to distal, the wrist; the carpal tunnel; the part of the palm extending from the exit of the carpal tunnel to the entrance of the fibrous flexor sheath suspended from the volar plate of the metacarpophalangeal joint; the portion of the osteofibrous canal of the fingers (digital canal) that is common to the deep and superficial flexor tendons and reaches halfway down the middle phalanx; and the distal segment of the same tunnel, which transmits only the flexor profundus tendon.

The tendon of the flexor pollicis longus also crosses five regions—the wrist; the carpal tunnel; the palmar region (or more accurately the thenar eminence); the digital canal, which extends from the opening of the proximal pulley at the volar plate of the metacarpophalangeal joint down to the exit of the "oblique pulley" halfway down the proximal phalanx (Doyle and Blythe, 1975); and the distal segment, which reaches the insertion of the tendon on the base of the distal phalanx.

The anatomical relations in these various zones are depicted in Figure 1–49. These diagrams show only too clearly that the danger of adhesions with the fixed structures is greater where the tendon runs within a fibrous sheath, and also that multiple tendon injuries tend to occur in regions where the tendons are bundled together, i.e., the wrist and the carpal tunnel.

The digital flexor tendons pass through the carpal tunnel before they fan out in the palm toward their respective digits. The flexor superficialis tendon inserts on the middle phalanx and the flexor profundus tendon on the distal

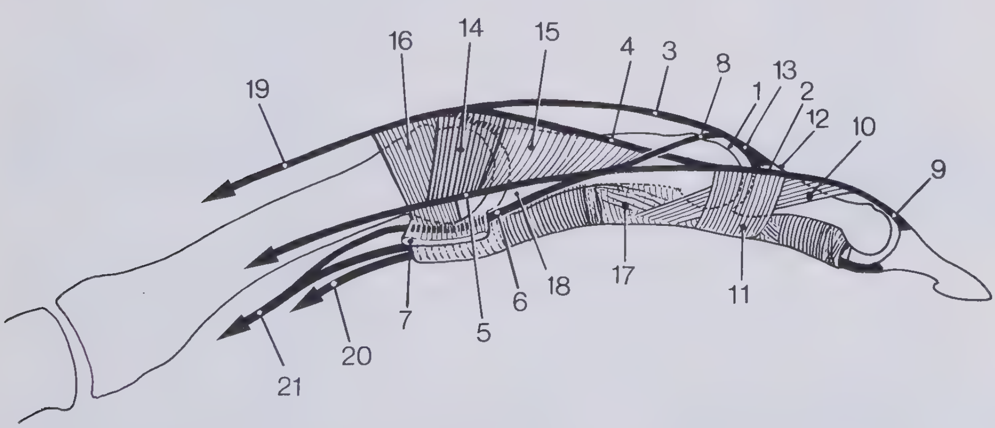


Figure 1–48. Diagrammatic view of the profile of a finger showing the insertions of the intrinsic and extrinsic muscles and the retinacular ligaments. There is a symmetry between the fibrous formations at the level of the metacarpophalangeal joint and the proximal interphalangeal joint. 1, Central or middle extensor tendon. 2, Lateral extensor tendon. 3, Central band of the long extensor. 4, Lateral band of the long extensor. 5, Interosseous tendon. 6, Lumbrical tendon. 7, Deep transverse intermetacarpal (or interglenoid) ligament. 8, Central band of the interosseous muscle. 9, Terminal extensor tendon. 10, Oblique retinacular ligament. 11, Transverse retinacular ligament. 12, Triangular ligament. 13, Insertion of the extensor digitorum into the second phalanx. 14, Transverse fibers of the interosseous hoods. 15, Oblique fibers of the interosseous hoods. 16, Sagittal bands. 17, Fibrous sheath of the flexor tendons. 18, Insertion of the interosseous muscle on the base of the proximal phalanx. 19, Tendon of the extensor digitorum. 20, Superficial flexor tendon. 21, Deep flexor tendon.

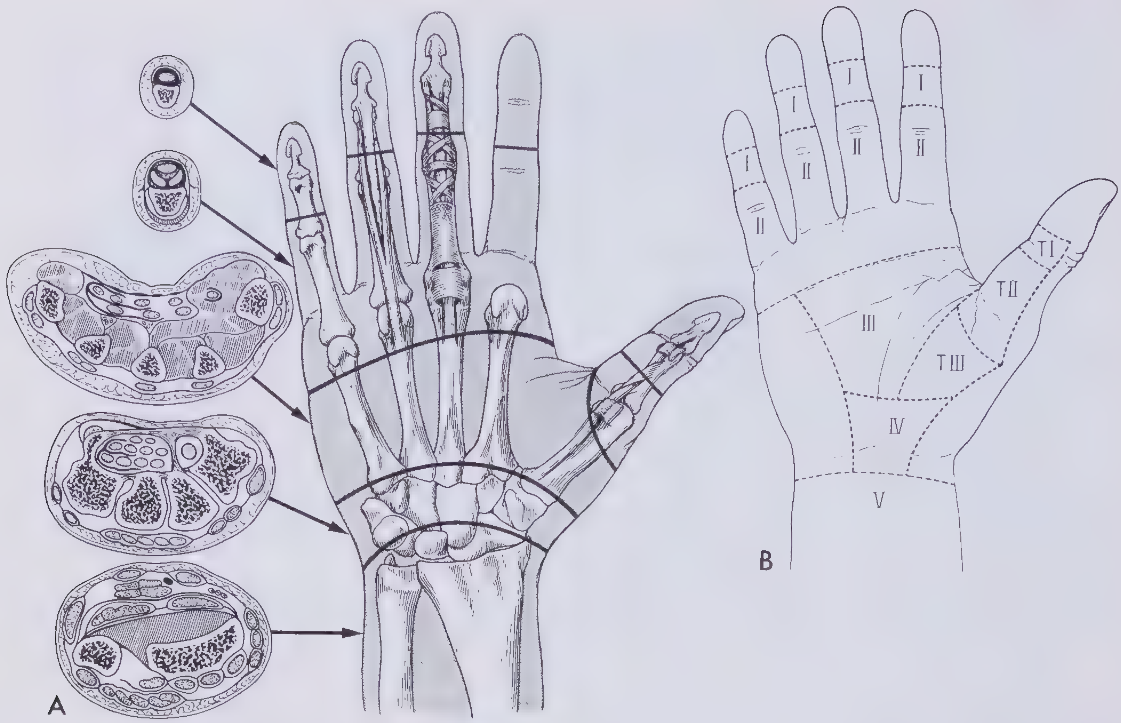


Figure 1–49. *A,* The five anatomical regions crossed by the flexor tendons of the fingers and thumb. The cross sections show the anatomical relations of the tendons. *B,* Topographical classification adopted by the International Federation of Societies for Surgery of the Hand. The regions crossed by the flexor pollicis longus tendon only are preceded by the letter T (thumb).

phalanx. In each digit the superficial and deep flexor tendons surrounded by their synovial sheaths for gliding are kept against the phalanges by their fibrous sheaths. Such a fibrous sheath plays an essential mechanical role in preventing divergence of the tendons from the axis of the digit in both the anteroposterior and lateral directions. This sheath does not have a homogeneous structure because it must adapt to the movement of the phalanges. One can distinguish several segments, some made up of dense annular fibers forming the pulleys and others made up of loose cruciform fibers, whose actions have been precisely described by Caffinière (1971), Brand et al. (1975), Hunter et al. (1980), and Doyle and Blythe (1975). (See Fig. 1–50).

At the level of the digital sheaths, the flexor tendons have a precarious blood supply. Lundborg has demonstrated the presence of several deprived zones—an "avascular segment" of the flexor superficialis just proximal to the chiasma, and two "avascular segments" of the flexor profundus proximal and distal to the vinculum longum (Fig. 1–51). In addition, at the level of the proximal interphalangeal joint, the flexor profundus tendon is vascularized only in its dorsal part, the anterior 1 mm. of the tendon, on which considerable pressure force is exerted. This segmental supply system, clearly inadequate in some areas, explains the difficulties of surgical repair while emphasizing the importance of the nutritional role of the synovial fluid.

We have already noted that the force of the flexor tendons is influenced by wrist position, but as shown by Hazelton et al. (1975), the percentage of total force allocated to each finger is constant, and the difference between the force exerted at the middle and distal phalanges is approximately 32 per cent (in favor of the middle phalanx) regardless of wrist position. The force of

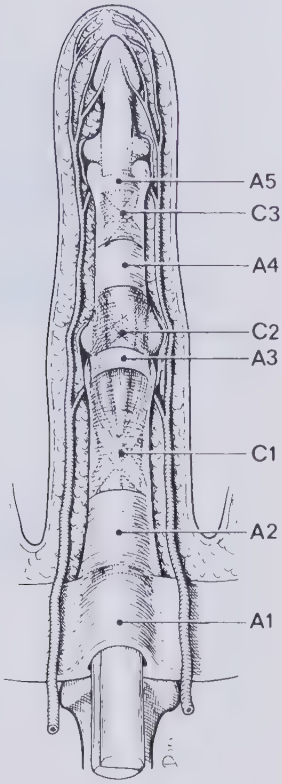


Figure 1–50. The digital flexor tendon sheath is formed by five annular pulleys and three cruciform bands. The second and the fourth annular pulleys are the most important for function. (Adapted from Doyle, J. R., and Blythe, W.: The finger flexor tendon sheath and pulleys: anatomy and reconstruction. *In* Symposium on Tendon Surgery in the Hand. St. Louis, The C. V. Mosby Company, 1975.).

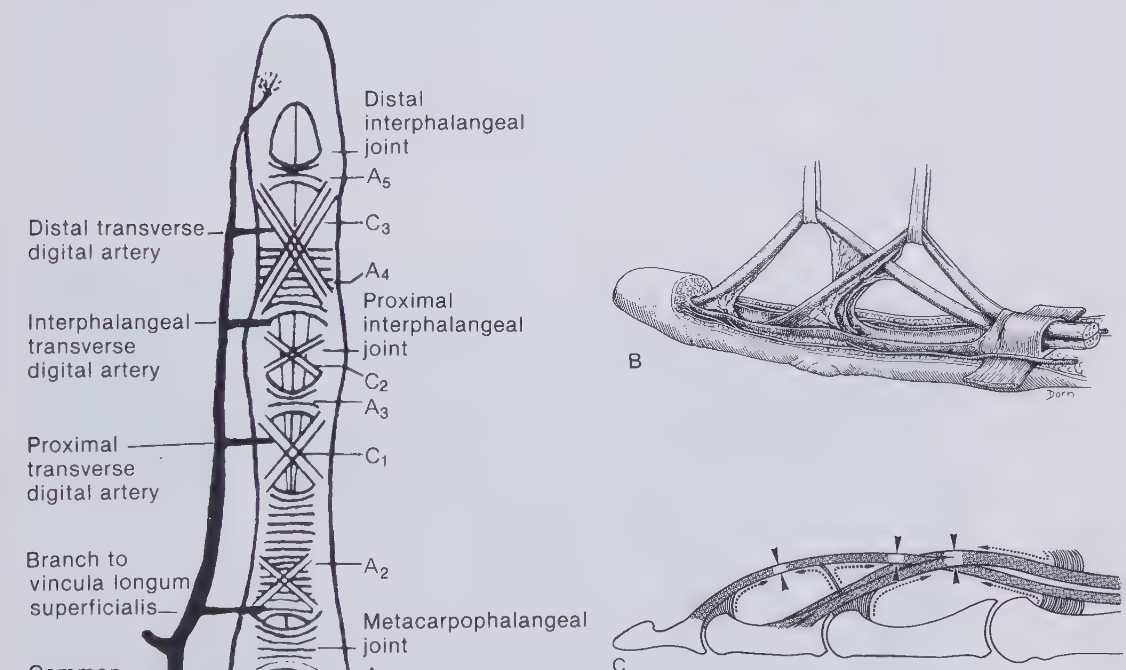


Figure 1–51. Blood supply of the flexor tendons in the digital tunnel. *A,* Four transverse tributaries enter the flexor retinaculum at the cruciate areas and feed the fine vincular system. *B,* The vincula of the flexor tendons in the digital sheath. One can see that complete removal of the flexor superficialis tendon may devascularize the flexor profundus tendon. *C,* The three "avascular" segments of the flexor tendons of the fingers. (*A* adapted from Ochiai, N., et al.: Vascular anatomy of flexor tendons. I. Vincular system and blood supply of the profundus tendon in the digital sheath. J. Hand Surg., *4*:321–330, 1979. *C* adapted from Lundborg, G., et al.: The vascularization of human flexor tendons within the digital synovial sheath region—structural and functional aspects. J. Hand Surg., *2*:417, 1977.)

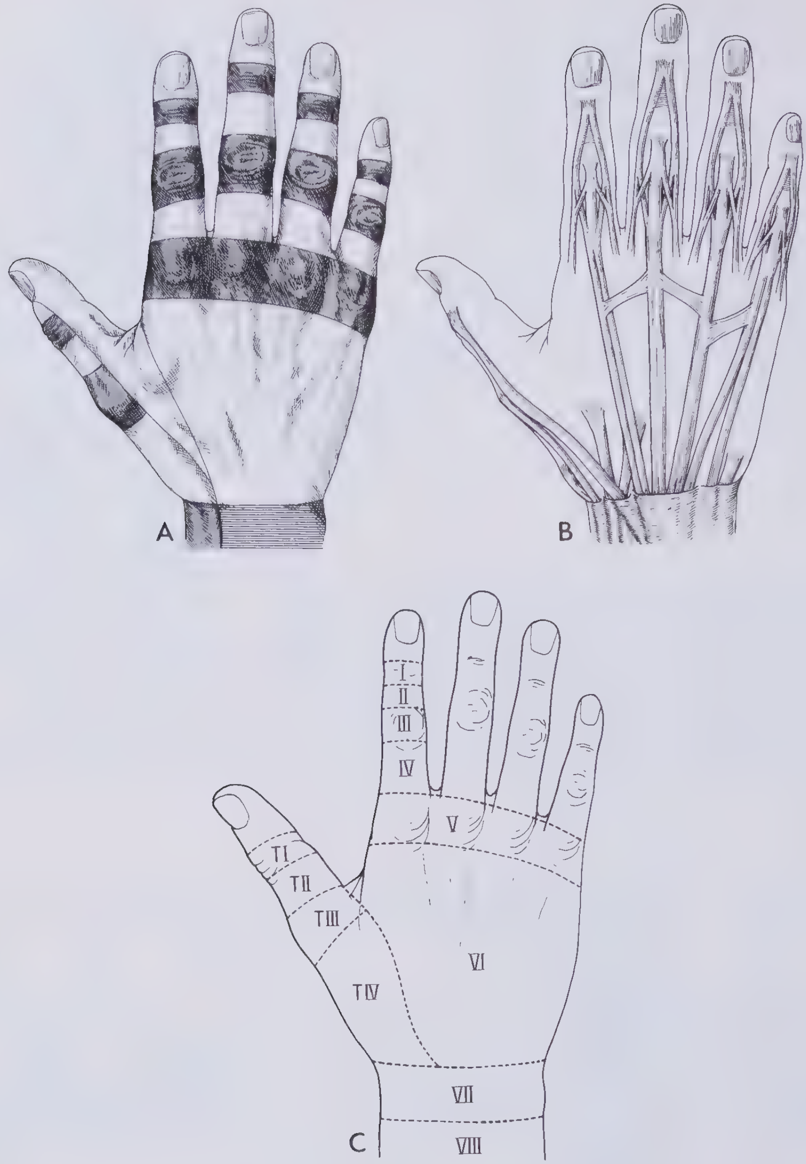


Figure 1–52. Extensor tendons of the hand. *A,* Division into topographic zones. *B,* Anatomy of the extrinsic extensor tendons. *C,* The extensor tendons of the fingers cross eight zones. The extensor tendons of the thumb cross six zones, four specific to the thumb, which are preceded by the letter T (thumb): TI, TII, TIII, and TIV. Two zones are shared with the extensor of the fingers: zones VII (wrist) and VIII (forearm).

flexion of the middle finger is the greatest and accounts for 33.5 per cent of the total force of flexion of the four fingers. The index and ring fingers account for 25 per cent each and the little finger for 16.5 per cent. Thus, the total force exerted by the two ulnar fingers at either the middle or the distal phalax is only 70 per cent of the total force of the radial fingers. The total force generated in power grip comes not only from the four fingers, but also from the force provided by the thumb and the thenar and hypothenar muscles. The long flexors of the digits essentially flex the distal articulations; it is only at the end of their excursion that they can act on the metacarpophalangeal joints, and eventually on the wrist if the fingers are stabilized in extension.

The Extensor Apparatus. Extensor tendons have the advantage of running an almost entirely extrasynovial course, which facilitates repair. However, they are also thin superficial structures, and when damaged they tend rapidly to become adherent to the underlying bones and joints. The excursion of the extensor tendons of the hand is considerably less than that of the flexors, and thus it is more difficult to compensate for a loss of length.

To describe the zones of injury, we use the nomenclature adopted at the Congress of the International Federation of Societies for Surgery of the Hand established in Rotterdam in 1979 (Fig. 1–52).

The extrinsic extensor system is more complex and has four sites of insertion (Fig. 1–53), the most proximal at the level of the interglenoid ligament provided on each side of the metacarpophalangeal articulation by the sagittal bands, and the most distal at the level of the base of the distal phalanx (Figs. 1–54, 1–55). The most important insertion is that of the central tendon into the base of the middle phalanx, the insertion at the base of the proximal phalanx being inconstant (Fig. 1–56). These multiple insertions at all the levels of the digital osseous chain distribute the action of the extrinsic extensor tendons to the three phalanges. However, they cannot insure complete extension of the finger. Under normal physiological conditions, isolated contraction of the long extensors extends only the proximal phalanx. The two distal phalanges remain flexed in a clawlike position that is accentuated in paralysis of the lower ulnar nerve. Indeed, the long extensors, whose range of movement is inferior to the range of the flexors, exhaust their action at the level of their proximal insertions, acting solely upon the first phalanx. To act upon the distal phalanges, the long extensors must lose their anchorage to the proximal phalanx, or the antagonist action of the long flexors must be suppressed. These are abnormal, pathological conditions. Nature has provided supplementary muscles—the intrinsic muscles—to relay the action of the long extensors and ensure the autonomy in extension of the distal phalanges.

The Intrinsic Apparatus. Flexion or extension at the level of the three articulations of the digits is not the result of a simple action of the long flexors

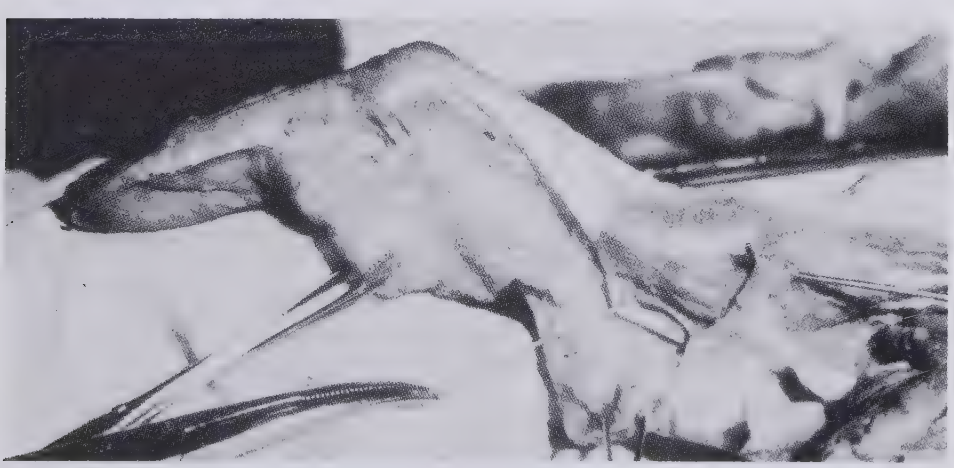


Figure 1–53. Lateral side of the right middle finger. At the level of the metacarpophalangeal joint the second dorsal interosseous muscle passes through a division of the sagittal bands (shown by the hook), which connect the extensor digitorum tendon to the interglenoid ligament. In front of this ligament the lumbrical muscle is pulled forward by the stitch. Note, on the dorsal aspect of the proximal phalanx, the extensor aponeurosis; more distally the oblique retinacular ligament crosses the lateral aspect of the proximal interphalangeal joint. The skin of the finger is put under tension to show the connecting ligaments between the dermis and the skeleton.

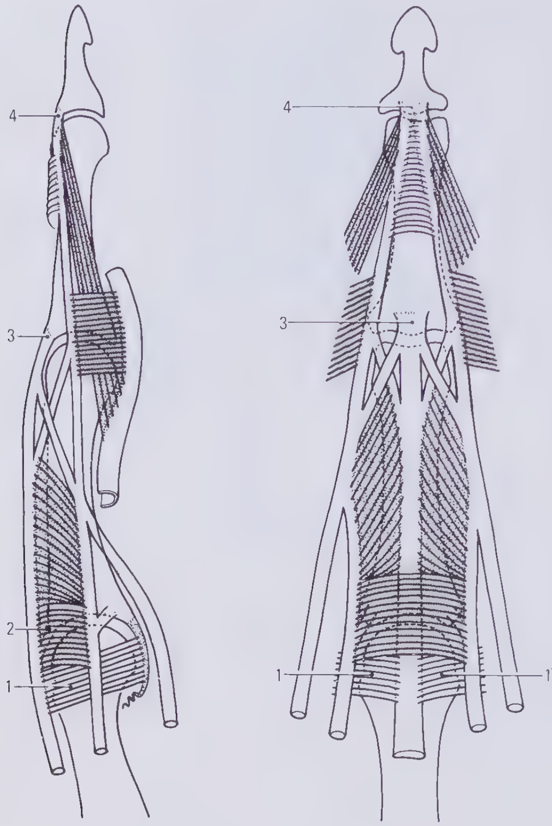


Figure 1–54. The main insertions of the extensor apparatus. The common aponeurosis of the extensor apparatus of the fingers is tensed by the extensor digitorum, by interosseous and lumbrical muscles, and by the retinacular ligaments. The four sites of insertion of the extensor digitorum tendon of the fingers are indicated in these diagrams: 1, The sagittal bands are the most proximal insertion of the extensor tendon. They run into the interglenoid ligament on each side of the metacarpophalangeal joint and contribute to the maintenance of the tendon in the dorsal axis of the finger. 2, Inconstant insertion of the extensor tendon into the base of the proximal phalanx. 3, The insertion of the middle (central) extensor tendon into the base of the middle phalanx is by far the most important. This middle (central) tendon is formed by the junction of the middle bands originating from both the intrinsic muscles and the extensor digitorum. 4, Insertion of the terminal extensor tendon into the distal phalanx. This tendon is formed by the two lateral extensor tendons. In turn, these lateral extensor tendons are formed by the junction of the lateral bands originating from the extensor digitorum tendon as well as from the intrinsic muscles.

or the long extensors. These two extrinsic systems, antagonistic to the movement of the distal phalanges but in effect collaborating in the extension of the proximal phalanx (Tubiana and Valentin, 1963), combine with the intrinsic muscular system, consisting of the interosseous and lumbrical muscles.

Galen (1854) discovered the anatomy of the interosseous muscles, but the famous anatomist from Pergame thought that their only action was flexion of the proximal phalanges of the digits. It was only in the sixteenth century that two pupils of Vesalius from Padova, Columbus and Fallope, gave a better anatomical description of these muscles. Columbus described the distal insertion of the lumbricals on the extensor digitorum communis, and Fallope established the action of the interosseous muscles as extensors of the distal phalanges. Winslow (1752) was more precise, for he found that the interosseous and lumbrical muscles act as flexors of the proximal phalanges and extensors of the two distal ones. However, all these investigators considered these muscles to be weak auxiliaries of the long flexors and extensors of the digits.

Duchenne (1867) studied the mechanism of the movements of the digits and demonstrated that the intrinsic muscles were indispensable to ensure the freedom of movement of each phalanx. It is interesting to read the description provided by Duchenne:*

*Translated by E. B. Kaplan.

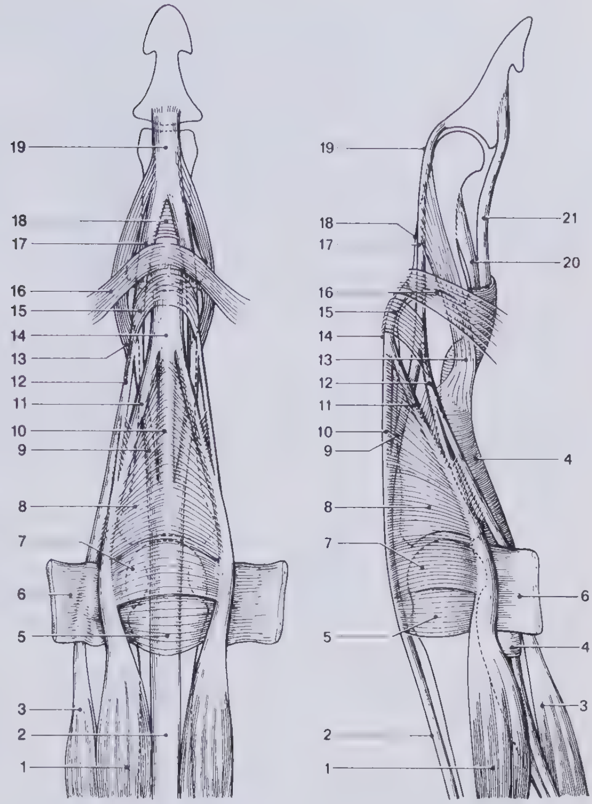


Figure 1–55. The extensor apparatus of the fingers—frontal and lateral views. 1, Interosseous muscle. 2, Extensor communis tendon. 3, Lumbrical muscle. 4, Flexor tendon fibrous sheath. 5, Sagittal band. 6, Intermetacarpal ligament. 7, Transverse fibers of interosseous hood. 8, Oblique fibers of hood. 9, Lateral band of extensor tendon. 10, Central or middle band of extensor tendon. 11, Central or middle band of interosseous tendon. 12, Lateral band of interosseous tendon. 13, Oblique retinacular ligament. 14, Middle extensor tendon. 15, Spiral fibers, 16, Transverse retinacular ligament. 17, Lateral extensor tendon. 18, Triangular ligament (or lamina). 19, Terminal extensor tendon.

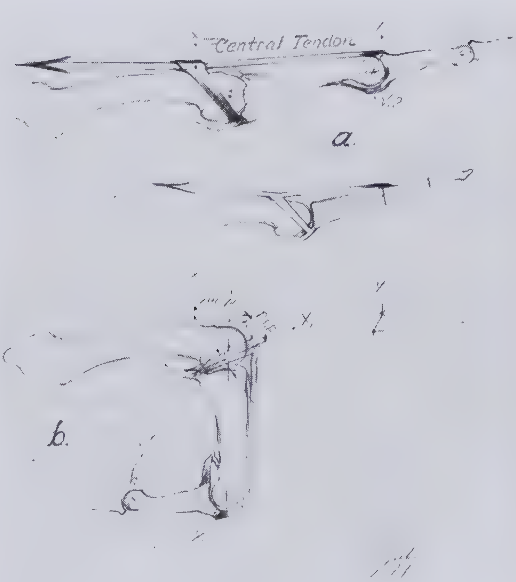


Figure 1–56. The middle or central extensor tendon, which inserts into the base of the second phalanx, has an extremely important action in the extension of all three phalanges: (1) It extends the middle phalanx on which it inserts, except when the metacarpophalangeal joint is in hyperextension (because the action of the extensor is then exhausted on its proximal insertions; shown in the middle diagram). (2) It contributes to extension of the proximal phalanx by pushing back its head when the proximal interphalangeal joint is flexed. (3) It helps extend the distal phalanx owing to the passive coordinating action of the oblique retinacular ligament. Note that in flexion the sagittal bands advance distally (x to x_1). This applies also to the interosseous hood.

It would be impossible to imagine a more ingenious mechanism favorable to simultaneous flexion of the proximal phalanx and extension of the two distal phalanges than presented in the anatomic arrangement of the terminal tendons of the [interosseous muscles] and lumbricals.

In the first part of their course from the head and anterolateral aspect of the metacarpal to the dorsal aspect of the head of the proximal phalanx, the tendons of the [interosseous muscles] and lumbricals have an oblique dorsal and distal direction so that during contraction of these muscles, motion occurs in the metacarpophalangeal joint, while the fixed point is at the distal end of the proximal phalanx. This arrangement produces flexion of the proximal phalanx in proportion to the force acting on the distal end of the lever represented by this phalanx.

In the second part of their course from the distal end of the proximal phalanx to the base of the distal phalanx, the same tendons pass over the dorsal aspect of the two distal phalanges, parallel to their longitudinal axis. As a result of this the contraction of the [interosseous muscles] produces only extension of the distal and then the middle phalanges. But the contraction of the [interosseous muscles] and lumbricals acts equally throughout the whole course of these tendons and thus produces simultaneously the two opposite movements of flexion of the proximal phalanx and extension of the two distal phalanges.

To understand well the marvelous ingenuity of the means used by nature to produce the movements and their mechanisms which I explained, it is necessary to obtain the same results by other mechanical combinations. This is exactly what I attempted.

I must confess that it appeared to me that the same movements could be produced by simpler means. Thus, I figured that if nature designed the common extensor of the fingers to extend the proximal phalanx only, why was it not sufficient to limit the insertion of the tendon to the dorsum of this phalanx? . . .

But why should there be a connection of the tendon of the [interosseous muscles] and lumbricals with the middle band of the common extensor? Would it not be simpler to have the tendon of these small muscles glide in an independent synovial sheath acting in the natural direction of the muscles? . . . However, that is where I noticed great difficulties in this mechanical arrangement; extension of the two distal phalanges, instead of being normal, as in the little finger (J) of which my finger (K) pulls the artificial [interosseous muscles] (11), [was] limited, and these phalanges hyperextended to such an extent that they formed an angle at the proximal interphalangeal joint. This is similar to the middle finger (1) in which my finger (K) pulls strongly the artificial dorsal [interosseous muscles] (10) [Fig. 1–57].

This mechanical experiment was of great value to me. It showed that the [interosseous muscles] and lumbricals must be limited or regulated in their action on the two distal phalanges without which they reproduce reverse action. . . .

This experiment finally taught me that the middle band of the tendon is continued to its insertion at the proximal and dorsal end of the middle phalanx with the only purpose to limit the action of the [interosseous muscles] and lumbricals.

Landsmeer (1955) showed that to control two joints of a chain in all positions, at least three muscles are necessary; all three may cross two joints, or two may be biarticular and one monoarticular. In a polyarticular chain of bones such as the fingers, equilibrium of each intercalated bone is insured by the balanced tensions of the three muscles. The proximal phalanx, which is a typical intercalated bone, is controlled by three muscular systems: two extrinsic muscles (anterior and posterior) and one diagonal intrinsic muscle (lumbrical and interosseous muscles; Fig. 1–58). For the middle phalanx, the third diagonal component is not a muscle but the oblique retinacular ligament, which inserts proximally into the flexor pulley and the neck of the proximal phalanx and distally into the lateral extensor tendons (Fig. 1–59).

Thus, two oblique structures cross the lateral aspects of the proximal and middle joints of the digital chain. Palmar to the axes of flexion of each joint proximally, they run dorsal to the axes distally. They can be tightened passively by two mechanisms: the extension of the joint they cross or the flexion of the distal joint. Their tension by the contraction of the long muscles, the tendons of which cross the anterior and posterior aspects of these joints, will trigger the

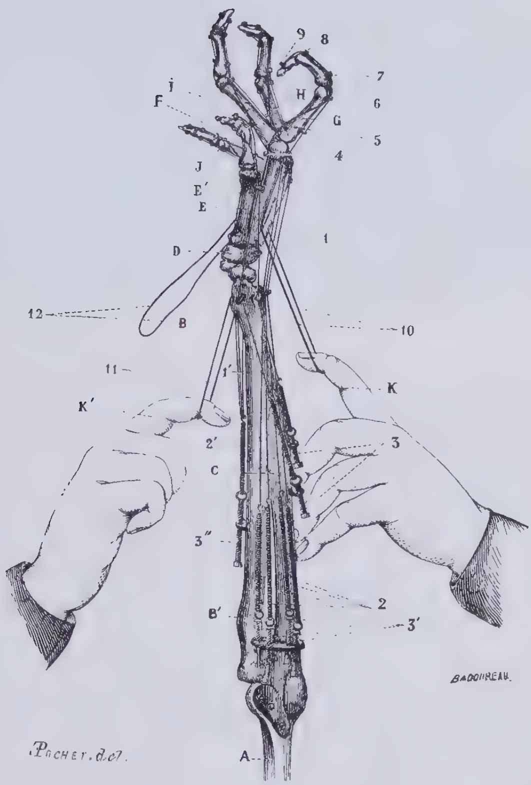


Figure 1–57. "The skeleton of a hand and forearm, with the help of artificial muscles (catgut, springs, and screws, which represent tendons attached and directed according to precise anatomical structure), can be made to reproduce natural motions of the phalanges, or imitate deformities following paralysis of various muscles. A, Distal end of humerus. B and B′, Radius. C, Ulna. D, Wrist. E, First metacarpal. E′, Second metacarpal. F, Thumb. G, Index finger. H, Fourth finger. I, Middle finger. J, Fifth finger. K, Finger of the operator's left hand. K′, Finger of the operator's right hand. 1, Artificial catgut tendons of the common extensors of the finger. 1′, Cords representing flexors of the fingers. 2 and 2′, Springs attached to the cords that represent the extensors and flexors of the fingers and that produce gradual tension or relaxation with the help of screws. 3, 3′, 3″, 4, 5, 6, 7, 8, and 9, Small rings fixed at different points of the metacarpals and phalanges in accordance with the anatomical orientation of the interosseous and lumbrical muscles and through which pass the cords representing these small muscles. 10, Cords representing the interosseous muscles of the middle finger (I), which is pulled by my left index finger (K). 11, Cords representing the interosseous muscles of the fifth finger (J), which are pulled by my right index finger. 12, Cords representing the interosseous muscles of the index finger in complete relaxation, imitating paralysis. By reason of this artificial paralysis the index finger (G) whose extensors and flexors are pulled by their corresponding springs assumes the attitude of a claw finger, as observed in individuals whose interosseous muscles are paralyzed and who attempt to extend their fingers." (From Duchenne, G. B.: Physiologie des Mouvements. Paris, J. B. Baillière, 1867.)

flexion of the corresponding joint. These oblique structures will stabilize the digital chains and will also determine the sequence of the movements of flexion and extension of the phalanges.

Each phalanx has a wide range of movement in flexion and extension (Fig. 1–60). Because flexion is insured by the exceptionally large excursion of the long flexors, that of the long extensors is much less important. Their action has to be relayed by the intrinsic muscles—the interosseous and lumbrical muscles.

The Interosseous Muscles. The structure of the interosseous muscles is particularly complex.

Each interosseous muscle is composed of a number of muscular bundles of different lengths, taking their origins on the lateral or palmar surfaces of the

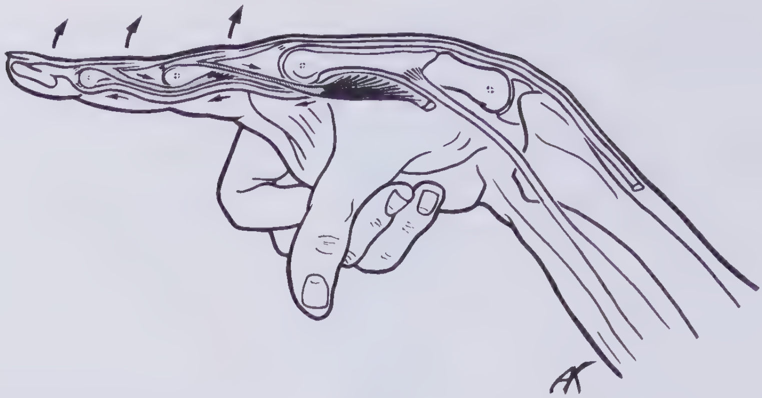


Figure 1–58. The two diagonal systems of digital extension. The first diagonal system is active: it is the lumbrical muscle (hatched) that reduces the tension on the deep flexor and increases the tension on the extensor apparatus leading to and completing the extension of the second and third phalanges. The second diagonal system is passive: it is the retinacular ligament (stippled) that passively contributes to the extension of the second phalanx on the third. The wrist is stabilized in flexion by the flexor carpi radialis, which augments the efficiency of the common extensor in its action of extending the first phalanx. (Diagram by Kapandji, modified from the hand of St. John the Baptist in the altar piece of Isenheim by Mathias Grunewald.)

metacarpal shafts. The muscular bundles have a relatively independent nerve supply, arising from the deep branch of the ulnar nerve. They continue into tendinous slips, entering the finger posterior to the interglenoid (deep transverse metacarpal) ligament. The tendinous slips insert distally at different levels in the fingers. These anatomical peculiarities allow for several classifications. Albinus (1724) classified the interosseous muscles according to their origins into three palmar adductors and four dorsal abductors of the fingers; this classification was accepted for almost 200 years (Fig. 1–61). They can also be classified according to their insertions into deep and superficial, proximal or distal (Salisbury, 1936; Stack, 1962).

The deep insertions are into the lateral tubercles on the base of the proximal phalanx and into the capsule of the metacarpophalangeal joint. They allow lateral movements of the fingers and prevent posterior dislocation of the muscle.

The superficial insertions occur at three separate levels in the finger:

1. One group of muscle bundles runs into the transverse fibers surrounding the posterior aspect of the metacarpophalangeal joint and into the base of the proximal phalanx and forms the interosseous hood. By means of the interosseous hood, the interosseous muscles flex the metacarpophalangeal joint.

2. A second group runs more distally over the dorsal aspect of the proximal phalanx. The oblique fibers blend with the central band of the extensor tendon and insert into the base of the middle phalanx, which they extend.

3. A third group of distal fibers blends with the fibers coming laterally from the lumbrical and runs into the lateral band of the extensor tendon to insert into the base of the distal phalanx.

This intricate arrangement, a veritable fibrous plexus on the dorsal aspect of the finger, forms a common extensor aponeurotic expansion, the extensor aponeurosis, activated at various levels by the tendons of the long extensors, the palmar or dorsal interosseous muscles, and the lumbricals and also anchored by fixed fibrous structures, such as the oblique retinacular ligaments, which act like a tenodesis (Fig. 1–62).

A

B

Figure 1–59. *A,* View from the radial side of a finger showing the elements of the extensor apparatus. A hook is passed under the interosseous head and the common extensor aponeurosis. At the base of the finger the three muscles acting on the aponeurosis are seen from top to bottom: the extensor digitorum tendon, the interosseous muscle, and the lumbrical muscle. *B,* Three dimensional view of a digit. The metacarpal has been removed, thus exposing the superficial flexor tendon (S) and the deep flexor tendon (P) entering the fibrous sheath (the first pulley). This sheath is attached to the anterior articular capsule or the volar plate (V.P.), to which the interglenoid ligament is attached laterally. The lumbrical muscle (1) passes in front of the interglenoid ligament while the tendons of the interosseous muscles (io) pass dorsally in the direction of the common extensor tendon. The central slip of the interosseous muscle forms (with the central slip of the common extensor) the middle extensor tendon or the central tendon (C.T.), whereas the lateral band of the interosseous forms the lateral extensor tendon with the lateral band of the common extensor, which inserts into the distal phalanx. This tendon receives from each side the oblique retinacular ligament (O.R. lig.), which obliquely crosses the proximal interphalangeal (P.I.P.) joint.

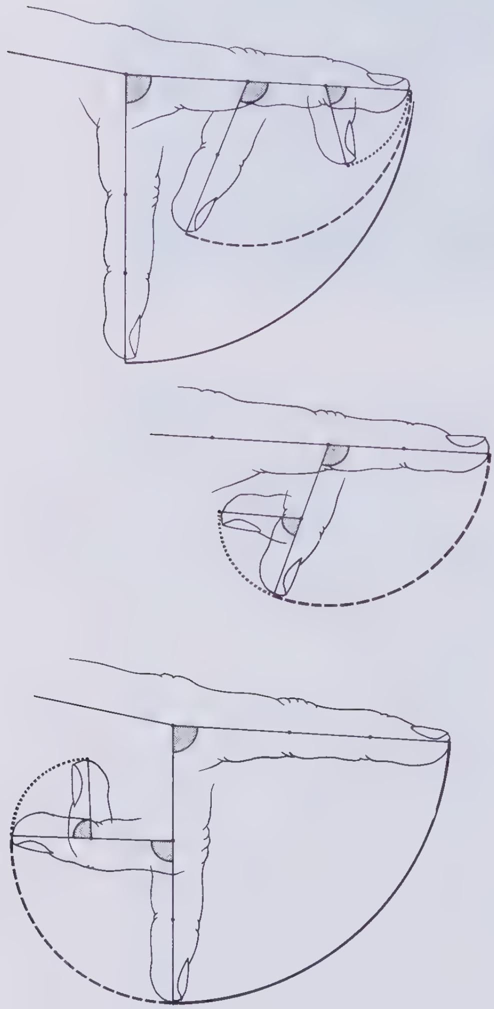


Figure 1–60. The ranges of flexion and extension of the different joints of the fingers. The large arc of flexion of the metacarpophalangeal joint, which represents 77 per cent of flexion of the finger, is under the influence of the intrinsic musculature (reinforced by the long flexors). The arcs of flexion of the interphalangeal joints are totally dependent on the strong extrinsic musculature. They represent only 23 per cent of the flexion, but their function is essential because they are responsible for the completion and strength of grasp. The whole movement describes an equiangular curve (Littler, 1977).

The movements of the two interphalangeal joints are thus bound by the common aponeurotic expansion and by the retinacular ligaments. The proximal and distal interphalangeal joints normally can move only in the same direction simultaneously; they form a functional unit, the interphalangeal system.

This is the general arrangement of the interosseous muscles. There are different patterns in the insertions of the interosseous and lumbrical muscles for each finger and even for each side of the finger, allowing greater functional individuality.

Because of the nonelastic structure of the extensor aponeurotic expansion,

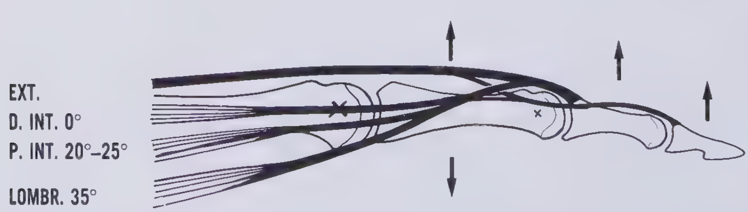


Figure 1–61. The angles of approach of the intrinsic tendons at the metacarpophalangeal level. The angle of approach of the lumbrical is the greatest. D. INT., dorsal interosseous muscle. P. INT., palmar interosseous muscle.

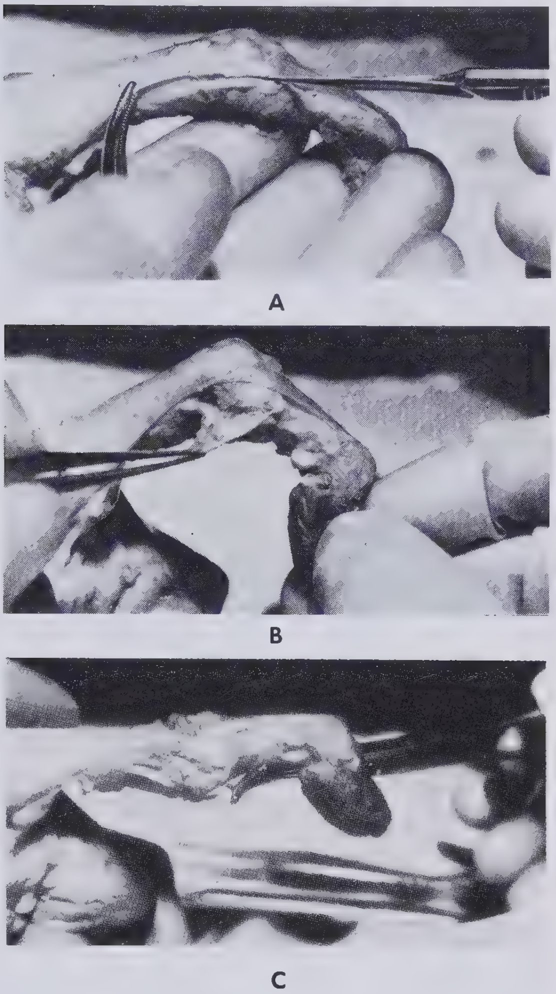


Figure 1–62. The oblique retinacular ligaments cross the proximal interphalangeal joint obliquely going from the fibrous sheath of the flexor tendons to the lateral extensor tendons. They coordinate extension between the proximal and distal phalangeal articulations. When the distal insertions of the oblique retinacular ligament are divided (*A* and *B*), the tenodesis effect is abolished. Thus, extension of the middle phalanx will not be followed by extension of the distal phalanx (*C*).

the lengthening that must occur when the fingers are flexed is achieved by a gliding movement in two directions, laterally and distally:

1. The lateral gliding of the extensor tendons. As the proximal interphalangeal joint flexes, the tendons move volarly over each side of the joint, resulting in a potential "boutonnière" deformity. This lateral gliding is checked dorsally by the triangular ligament and the spiral fibers (Fig. 1–55).

2. The distal gliding is especially important at the level of the metacarpophalangeal joints. It is made possible and later checked by the peculiarities of the proximal insertions of the long extensor. The sagittal bands, attached into the volar plates of the metacarpophalangeal joints, are directed obliquely forward and distally when the joint is extended (see Fig. 1–56). Their dorsal attachments are then proximal to the joint; in full flexion they cover the joint. The extensor tendon is attached to the base of the proximal phalanx by means of a long thin insertion, which is relaxed during flexion of the interphalangeal joints and taut during extension (Fig. 1–63).

The interosseous hood is displaced distally during flexion. This gliding movement extends about 16 mm. at the level of the long finger. The hood covers the metacarpal head in extension but slides distal to the joint in flexion. This gliding has important physiological results:

1. The interosseous muscles cannot actively trigger flexion of the metacarpophalangeal joint by means of their hood attachments. They need a starter to

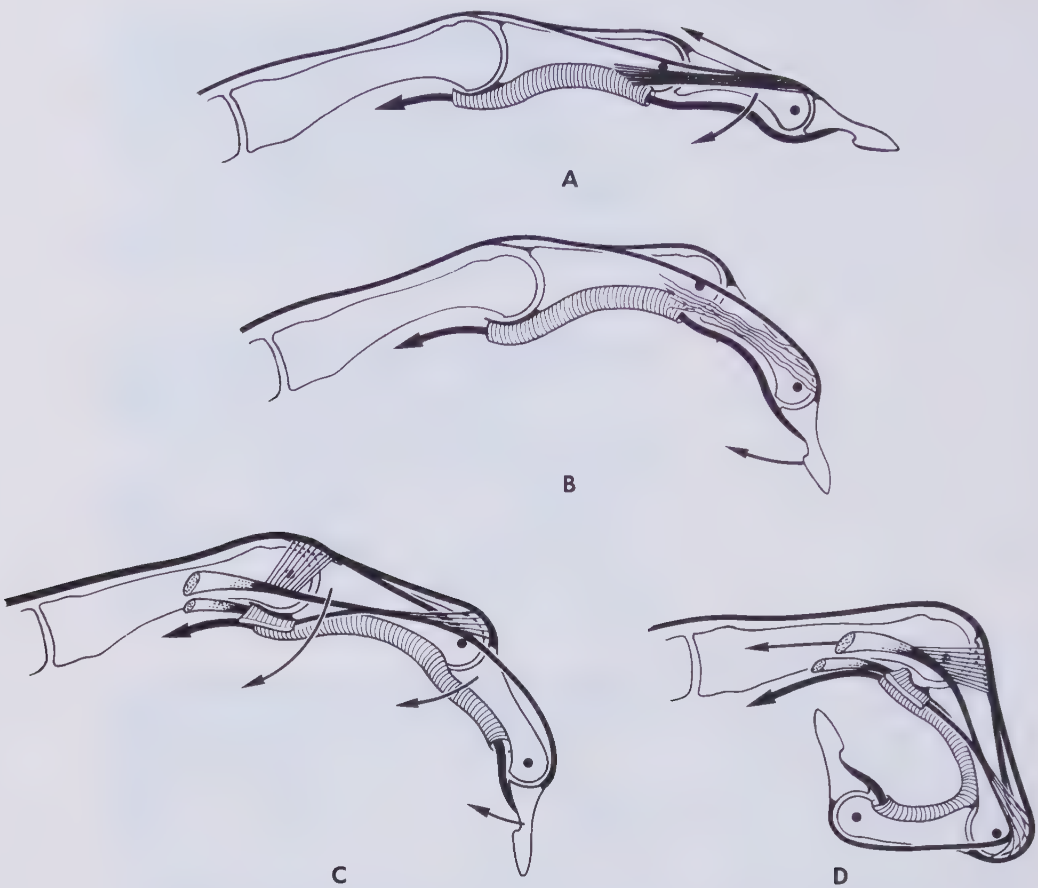


Figure 1–63. The order of flexion of the phalanges is controlled by a complex mechanism. *A,* The flexor profundus and extensor digitorum contract simultaneously at the beginning of flexion; the extensor acts as a braking mechanism. The oblique retinacular ligament, which is put under tension by flexion of the distal phalanx, acts as an active tenodesis to initiate flexion of the proximal interphalangeal joint. *B,* As the proximal interphalangeal joint flexes, the tension in the oblique retinacular ligament decreases, thereby allowing for more flexion at the distal joint. *C,* Flexion of the proximal interphalangeal joint puts the lumbrical and interosseous tendons, which cross obliquely in front of the axis of the metacarpophalangeal joint, under tension, and this initiates flexion of the metacarpophalangeal joint. *D,* Flexion of the metacarpophalangeal joint displaces the interosseous hood distally; once distal to the joint, it can act as a flexor of the proximal phalanx. Thus, two structures that cross the joint obliquely at two successive levels have a similar tenodesis effect on the digital kinetic chain. Both are palmar to the axis of flexion proximally and dorsal to the axis distally. An increase in tension in these structures caused by the action of the extrinsic muscles will initiate flexion of the phalanx they cross. This tension can be brought about by two different mechanisms, i.e., flexion of the distal joint or flexion of the proximal joint.

place the hood in a favorable position, distal to the joint. Once in place, they can fully flex the metacarpophalangeal joints and their momentum will increase with flexion (Fig. 1–63).

2. Bunnell (1956) had already noted that the interosseous muscles cannot extend the interphalangeal joints unless the metacarpophalangeal joints are extended. If the metacarpophalangeal joint is flexed, the contraction of the interosseous muscles tightens the hood against the dorsum of the proximal phalanx and prevents it from gliding proximally. Sometimes certain distal bundles (the equivalents of the lumbricals) are capable, however, of extending the distal phalanges even if the metacarpophalangeal joint is flexed, because they are relatively free from the hood.

3. During complete flexion of the metacarpophalangeal and proximal interphalangeal joints the extensor apparatus glides distally 20 to 24 mm. (depending on the finger). The extensors fail, therefore, to control the extension of the distal phalanx from this position.

Two points should be stressed about the complex actions of the interosseous muscles:

1. The movements of the phalanges can be independent of the position of the wrist by virtue of the interosseous muscles.

2. The position of the metacarpophalangeal joint determines the application of the forces of the interosseous muscles. In flexion of the metacarpophalangeal joint, the interosseous muscles act upon the hood and increase the flexion; during extension of the metacarpophalangeal joint, the contraction of the interosseous muscles is transmitted via the lateral bands of the extensor aponeurosis and contributes to the extension of the distal phalanges.

Each of the two systems, the long extensors and the intrinsic muscles, can extend the interphalangeal articulations, provided the muscles and tendons move freely and the metacarpophalangeal articulations cannot be thrown into hyperextension. This "stabilization" of the metacarpophalangeal articulation is normally the result of the action of the interosseous muscles. Should they be paralyzed, the long extensors act unopposed at the level of their proximal insertions (the sagittal bands and the inconstant insertion on the base of the proximal phalanx) and hyperextend the metacarpophalangeal articulations. This precludes any further action in the interphalangeal joints. Holding the metacarpophalangeal joints in slight flexion, as described by Bouvier in 1851, allows extension of the distal phalanges. Complete extension of the phalanges is produced if hyperextension of the proximal phalanx is prevented or if the two flexor tendons are divided (Fig. 1–64). Then only with traction on the long extensor is it possible to extend all the phalanges.

Various surgical procedures can prevent hyperextension of the metacarpophalangeal joints—tendon transfers, tenodesis, and capsulodesis—so that the long extensors can be allowed to extend the distal phalanges. Correction of the muscular imbalance is not sufficient to re-establish function after paralysis of the intrinsic muscles of the fingers. Besides correcting the deformities, the reconstruction of prehension requires tendon transfers strong enough to ensure useful flexion of the metacarpophalangeal joints and good abduction of the index finger to resist the pressure of the thumb.

The Lumbrical Muscles. The lumbrical muscles, whose tendons pass volar to the transverse interglenoid ligament, can also stabilize the metacarpophalangeal joints. Thus, in an isolated ulnar nerve paralysis, the radial lumbrical muscles, innervated by the median nerve, prevent hyperextension of the proximal phalanx and subsequent clawing of the index and middle fingers. However, the lumbricals appear primarily to be interphalangeal extensors, following which (and only then) they could possibly act as metacarpophalangeal flexors (Backhouse, 1968). The action of these small slender muscles between the flexor profundus tendons and the extensor apparatus is subtle: they participate in extension of the distal phalanges by pulling distally on the flexor profundus tendon when this muscle is at rest. As has been shown by Long, this permits a reduction of the viscoelastic resistance of the flexor profundus and indirectly facilitates the action of the common extensor on the distal phalanges. Contraction of the lumbrical muscles, whose relatively free play is little impaired by attachments to the dorsal hood, also contributes directly to the extension of the distal phalanges, regardless of the position of the metacarpophalangeal

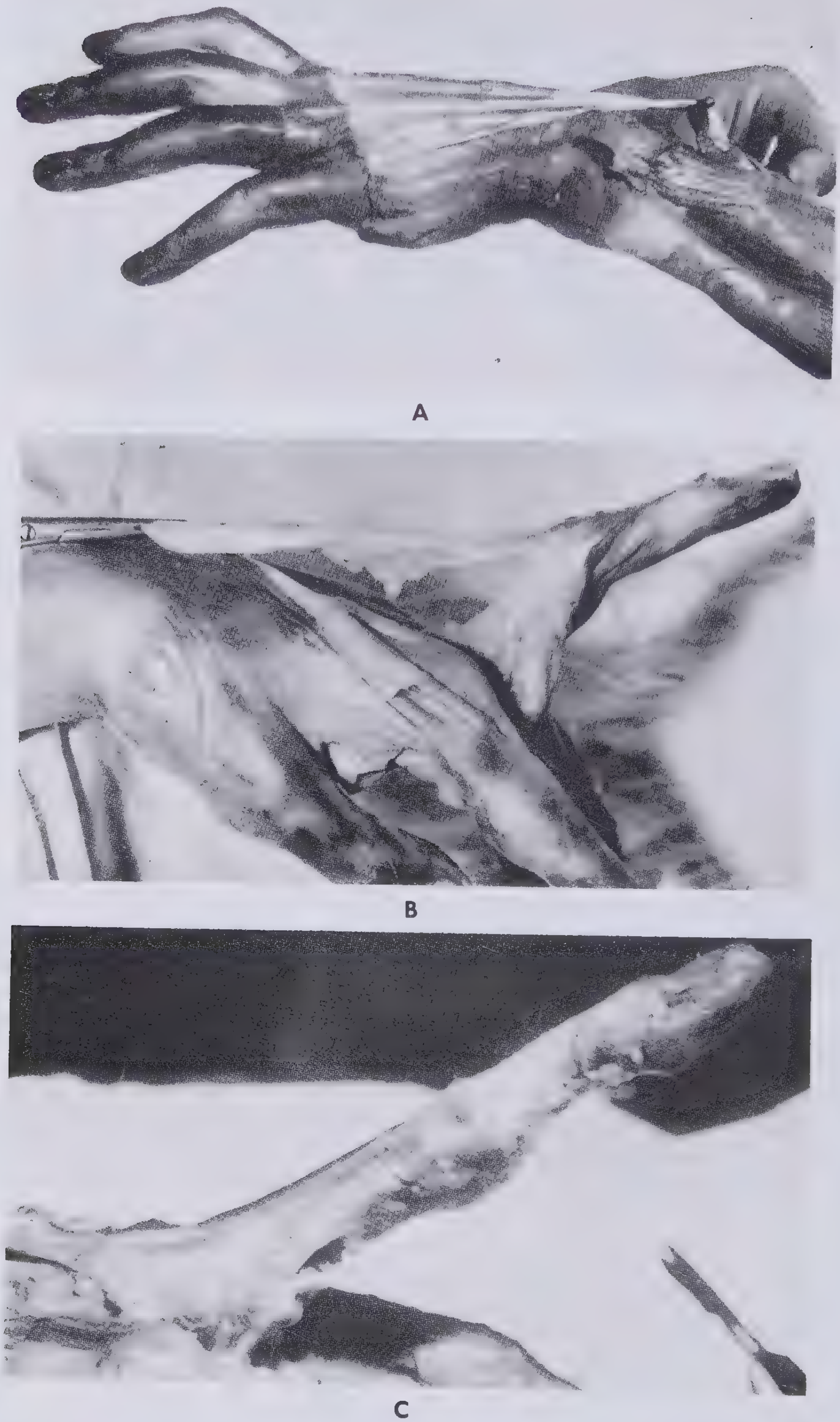


Figure 1–64. *A*, Traction on the extensor digitorum puts the metacarpophalangeal joint into hyperextension and the interphalangeal joints into flexion. *B*, Traction on the extensor communis if the proximal insertions are divided will put the interphalangeal joints into full extension. *C*, If the flexors are divided, traction on the extensor digitorum will extend all the joints.

joint, whether they are extended or flexed. By contrast, the interosseous muscles have a decreasing extensor effect at the interphalangeal joints as flexion of the metacarpophalangeal joint increases. This explains why, despite their feebleness, these muscles can form an "active diagonal system" between the flexors and extensors at the proximal part of the finger. To take a comparison from the field of electronics, one can say that they have a "transistor effect" (Kapandji).

Thus these muscles, which have the same innervation as the corresponding flexor profundus, play a coordinating role between the extensor and flexor systems. Rabischong (1963) demonstrated the richness of the sensory receptors at their level, making these small and weak muscles true proprioceptive organs.

Sequences of Flexion and Extension Movements of the Phalanges

The extremity of the finger describes in flexion a curve with a progressively diminishing radius, which allows the closing finger to wrap around objects of decreasing diameter (Fig. 1–63).

The basal joint of the finger, the metacarpophalangeal joint, according to Littler describes the largest segment (77 per cent) of the arch of flexion; the middle joint, the proximal interphalangeal joint, contributes 20 per cent and the distal interphalangeal joint, only 3 per cent (Fig. 1–60).

Flexion of the fingers begins normally at the level of the proximal interphalangeal joint, followed by the metacarpophalangeal and distal interphalangeal joints. The distal interphalangeal joint flexes more slowly than the proximal interphalangeal joint, and its flexion is completed only at the end of the movement, locking the grip.

The upsetting of this rhythm of flexion, as in paralysis of the ulnar nerve when the distal phalanx flexes first, strongly impairs the grip, especially of larger objects. It is incorrect to assume that the middle phalanx flexes first because the flexor superficialis is the first muscle to contract. The electromyography studies of Long and Brown (1964) demonstrated that during unopposed flexion of the fingers, only the flexor digitorum profundus and the extensor digitorum contract at the onset of the movement. The extensor progressively relaxes afterward, to allow for the flexion of the metacarpophalangeal joint, and acts as a brake throughout the movement of flexion. The flexor superficialis does not contract during unopposed flexion; its action predominates during flexion against resistance. The lumbrical muscles also do not contract during unopposed flexion.

The explanation for these paradoxical phenomena was given by Landsmeer (1949), Landsmeer and Long (1965), Kaplan (1954, 1965), Stack (1962), and Long and Brown (1964). With Valentin (1962) we studied the rhythm of flexion and extension of the fingers by slow motion films, mechanical models, and cadaver specimens. Our studies confirmed their findings.

As the flexor digitorum profundus contracts, the oblique bands of the retinacular ligaments tighten and cause flexion of the middle phalanx (Fig. 1–63). Because the oblique retinacular ligaments insert into the terminal extensor tendon and cross the lateral aspects of the proximal interphalangeal joint obliquely, they provide a long lever arm that moves the proximal interphalangeal joint more than the distal interphalangeal joint. The extensor, contracting simultaneously with the flexor digitorum profundus, prevents the flexion of the distal interphalangeal joint. The continuous, more rapid flexion of the proximal

interphalangeal joint progressively relaxes the tension of the oblique retinacular ligaments and allows complete flexion of the distal interphalangeal joint.

The active flexion of the proximal interphalangeal joint starts the flexion of the metacarpophalangeal joint. This happens because flexion tightens the tendons of the interosseous and lumbrical muscles, and passive flexion occurs as these tendons run in front of the axis of the metacarpophalangeal joint. Then the interosseous muscles can start acting by means of their attachments into the hood. In paralysis of the ulnar nerve, as the viscoelastic resistance of the intrinsic muscles disappears, the action of the extrinsic muscles does not flex the metacarpophalangeal joint; they cause hyperextension of the metacarpophalangeal joint and clawlike flexion of the fingers. In a normal hand, the tenodesis effect of the intrinsic tendons can be overcome by voluntary contraction of the long flexors. The two distal phalanges can be hooked in full flexion while maintaining the metacarpophalangeal joint in extension.

Extension of the fingers starts at the level of the metacarpophalangeal joint. Anatomical studies and electromyography demonstrate that isolated contraction of the extensor results in a clawlike position and not a complete extension of the digital chain (Fig. 1–64). The extensor digitorum exhausts its action at the level of the metacarpophalangeal joint, which it hyperextends by means of its proximal insertions, the sagittal bands. Division of the sagittal bands allows the extensors to fully extend the interphalangeal joints, together with the metacarpophalangeal joint. The viscoelastic resistance of the long flexors increases in hyperextension of the metacarpophalangeal joint and flexes the distal phalanges. Contraction of the lumbrical suppresses this resistance and corrects the claw position.

Extension of the proximal interphalangeal joint by traction of the middle band of the extensor tenses the oblique band of the retinacular ligament and starts the extension of the distal phalanx. The movement is completed by the combined actions of the extensor communis and the intrinsic muscles.

In cases of paralysis or division of the flexor tendons, traction on the extensor tendon causes complete extension of the fingers, but in a sequence contrary to the normal one: The distal interphalangeal joint extends first, followed by the proximal interphalangeal and metacarpophalangeal joints. Thus, the braking action of the flexors controls the sequence of the extension of the phalanges.

In conclusion, the three phalanges constitute a kinetic chain, and lesions of the extensor apparatus at one level may alter the balance of the whole finger (Fig. 1–65).

Movements of the Thumb

The wide range of motion of the column of the thumb allows opposition to the palm and to the other digits. This very special movement, which contributes to the uniqueness of man's hand, is the result of:

1. The forward tilt of the radial carpometacarpal column (Fig. 1–66).
2. The configuration of the trapeziometacarpal, metacarpophalangeal, and interphalangeal articular surfaces.
3. Muscular traction.
4. Control by ligaments. The dorsal ligaments of the trapeziometacarpal joint form a unit with the thenar muscles that partially determines the movement of the first metacarpal (Zancolli, 1977).

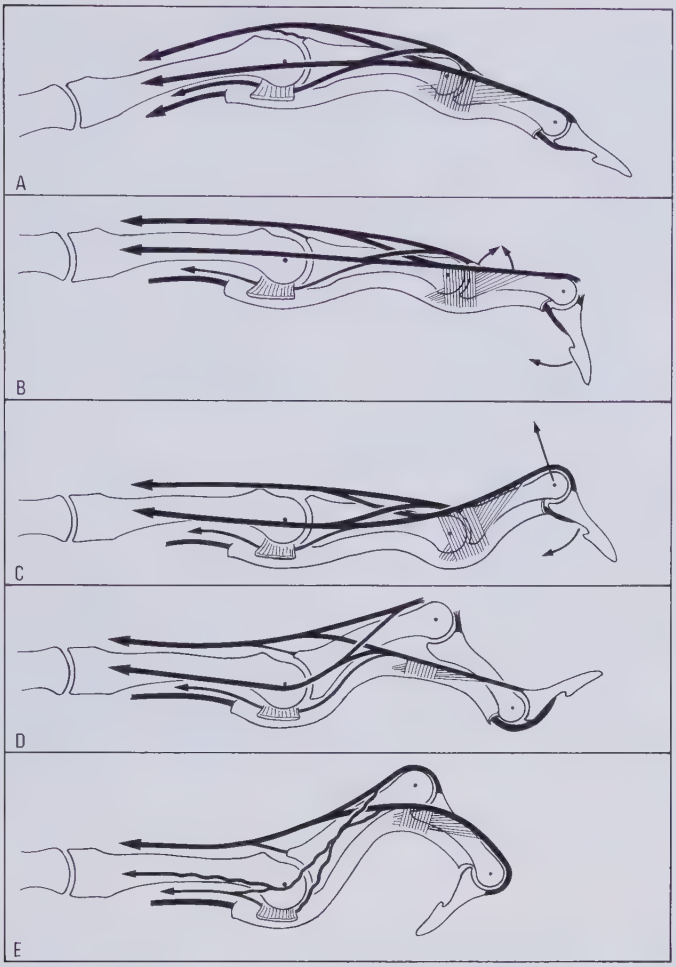


Figure 1–65. The digital kinetic chain and its deformities. *A,* Normal balance of the chain. *B,* Mallet deformity. *C,* Swan neck deformity. *D,* Boutonnière deformity. *E,* Claw deformity.

The three articulations of this chain have different sectors of mobility. The more proximal they are, the more directions of mobility they have.

The Interphalangeal Articulation. The interphalangeal articulation is a trochlear type of articulation, allowing mainly flexion and extension; the flexion is accompanied by a slight degree of rotation in pronation. Lack of extension of this joint, if greater than 15 degrees, is functionally more disabling than lack of flexion.

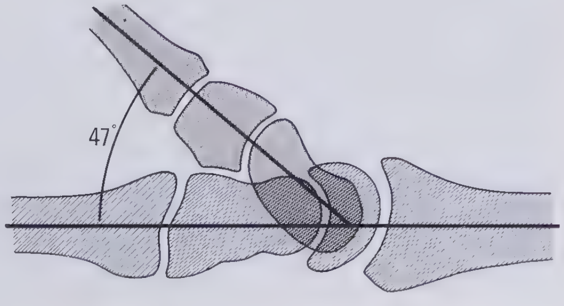


Figure 1–66. The carpometacarpal ray of the thumb is anterior to the plane of the other metacarpals and makes an angle of about 47 degrees with the second ray.

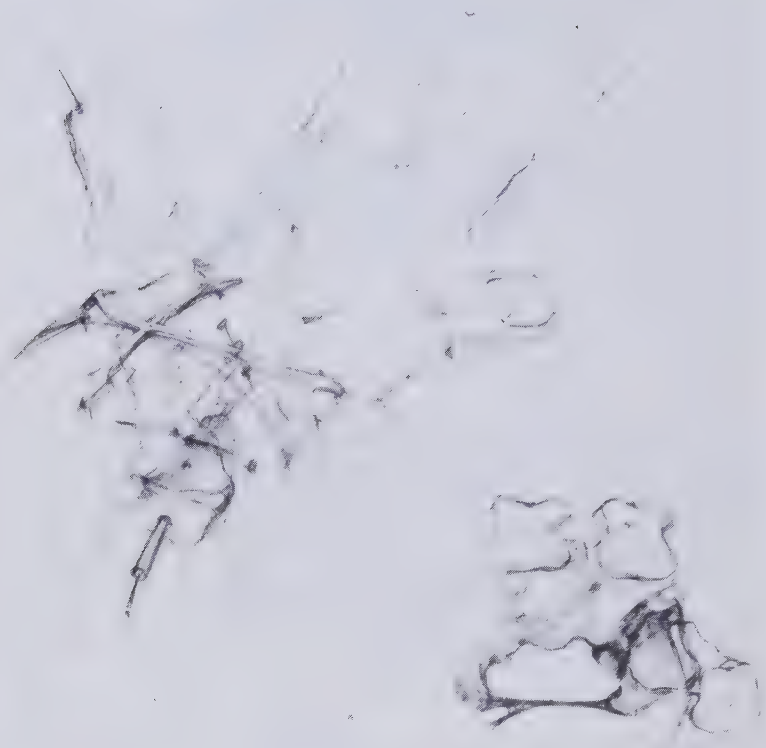


Figure 1–67. The movements of the first metacarpal in anteposition and flexion-adduction are accompanied by an "automatic" longitudinal rotation in pronation.

The Metacarpophalangeal Articulation. The metacarpophalangeal articulation is of a condylar type. In addition, it is capable of small lateral movements, especially to the radial side. Flexion is always accompanied by radial deviation and pronation, thus stretching the ulnar metacarpophalangeal ligament. This helps to ensure stability of this articulation, which is more important than movement from a functional viewpoint.

The Trapeziometacarpal Articulation. Because of its saddle shaped articular surface and its peculiar ligamentous structure, the trapeziometacarpal articulation has great liberty of movement, but its stability requirements are just as exacting to ensure a firm grip (Fig. 1–67).

The stability of the trapeziometacarpal joint does not depend upon any contribution from the saddle shape of its articular surfaces except in anteposition and pronation when the articular surfaces are congruent. This stability is provided by a system of ligaments designed in such a way that mobility is not altered. It comprises essentially a strong ulnar ligament from the base of the first metacarpal to the second metacarpal and to the trapezoid (it is this ligament that resists in a Bennett fracture) and a couple of oblique ligaments (anterior and posterior), which were described by Haines (1944) and whose role was accurately defined by Caffinière (1970) and Pieron (1973). The oblique ligaments tighten and thus become efficient as stabilizers in complete pronation of the thumb, i.e., in the position of the thumb-digital grip.

The radial side of the joint has a much weaker ligament. Thus, there is an intrinsic instability at the level where the pressure is very high; this pressure is

proportional to the force of the grip at the distal end of the thumb and to the length of the lever arm (Fig. 1–68).

Cooney and Chao (1977) found that the joint compression forces during simple pinch averaged 3.0 kg. of force at the interphalangeal joint, 5.4 kg. at the metacarpophalangeal joint, and 12.0 kg. at the carpometacarpal joint. Compression forces of up to 120 kg. may occur at the carpometacarpal joint during strong grasp. Stability here is dynamically provided by a single structure, the tendon of the abductor pollicis longus, which has stabilizing function only when the first metacarpal is abducted. In adduction, the long abductor increases the risk of subluxation of this joint.

This design of the trapeziometacarpal joint accounts for the functional efficiency of the joint. It also explains the frequent pathological subluxations occurring after trauma, in rheumatoid arthritis, and after trapeziometacarpal joint implants.

The movements of the three articulations of this functional unit, which make up the thumb ray, are partially able to compensate for each other in flexion-adduction or extension-abduction. However, bringing the thumb ray in front of the plane of the palm (anteposition) is a movement of the first metacarpal that is unique to that carpometacarpal joint.

The movements of the thumb have been the object of numerous analyses, at times controversial. The articles by MacConaill (1941), Napier (1955), Kaplan (1954), Kapandji (1963, 1972). Valentin (1962), Ebskov (1970), Caffinière (1970), Pieron (1973), and Zancolli (1977) should be noted. Each of these studies has an original idea and contributes to our understanding of this complex mechanism.

Terminology

The complexity of these movements explains the confusion in terminology. Each author justifies his own terminology by advocating a mechanism or making

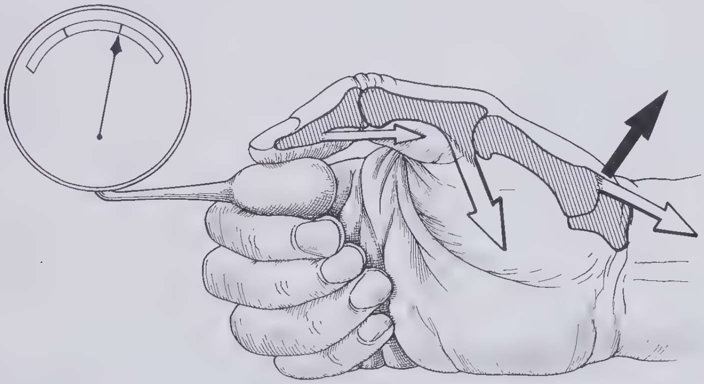


Figure 1–68. The strength of grip at the distal phalanx of the thumb depends on the stability of the thumb column and the force of the adductor muscles. The two muscles that provide most of the power in grip are the flexor pollicis longus and the adductor pollicis. The flexor pollicis longus works as an adductor and a flexor of the metacarpophalangeal joint when the interphalangeal joint is stabilized in extension. The adductor pollicis plays a very important role in the strength of grip. This is noted especially in ulnar nerve palsies in which there is a considerable loss of force. The stability of the thumb column is provided by the capsuloligamentous structures as well as by muscles, essentially the adductor pollicis and the flexor pollicis brevis at the metacarpophalangeal joint, and by the abductor pollicis longus at the trapeziometacarpal joint when the first metacarpal is abducted. In terminal grip a significant compression force is exerted at the trapeziometacarpal joint. Cooney and Chao (1977) showed this to be 12 kg., with a terminal force of 1 kg. Thus, it is easy to understand that the tendency for radial subluxation of the base of the first metacarpal (black arrow) is much greater when the first metacarpal is abducted.

an analogy with the movements of the fingers or with the muscle responsible for the motion. What is required of a terminology is not only a justification, but above all a simplification. Such a terminology should be clear, as universal as possible in its terms, and acceptable to all. We are far from this goal in discussing movements of the thumb.

The difficulty with terminology describing thumb movements arises from two causes. The first is conceptual: Some authors describe abduction as any movement of separation of the first metacarpal from the second metacarpal and specify the direction of movement by an adjective, such as radial abduction or palmar abduction. This is the terminology adopted by the International Federation of Societies of Hand Surgery. This definition of each movement by necessity employs two terms.

Another international society, the International Anatomical Society, has adopted the terms abduction and adduction to describe the movements in the sagittal plane and flexion and extension for movements in the frontal planes (Nomina Anatomica, 1960). However, Rabischong (1971) in an attempt at clarification prefers to distinguish the movements of the phalangeal segments from those of the first metacarpal. According to him, the terms flexion and extension should be reserved to designate only movements of the phalanges.

The second difficulty is in the anatomical realm: As demonstrated by Kapandji (1972), the axes of the trapeziometacarpal articulation are oblique in relation to the planes of reference. In order to study the movements of this articulation, a special reference system must be used, the trapezial system, which may be measured precisely only by radiography.

It is understandable that in the presence of these difficulties in selecting a terminology authors avoid the use of traditional terms and attempt to define the movements of the thumb according to its trajectory in relation to the index metacarpal. This is the solution adopted by Caffinière (1970) and by Ebskov (1970). In its larger elliptical path the distal end of the thumb metacarpal realizes a motion of "circumduction"; that is to say, it inscribes a conical segment at the farthest distance from the second metacarpal. In its smaller elliptical path of circumduction, it moves as close as possible to the second metacarpal.

In an effort to be precise, we have to distinguish between terms defining a set position of the thumb metacarpal in space and terms defining the movements.

Terms Defining a Set Position. We will use the two static coordinates proposed by Duparc et al. (1971) with the following nomenclature and definitions:

The angle of separation is the angle formed between the thumb and index metacarpal in the sagittal plane (Fig. 1–69).

The angle of circumduction (the term we prefer to the term "angle of spatial rotation," which the last mentioned authors use) is the angle formed between two planes—one plane formed by the thumb and index metacarpal and the other (the reference plane) formed by the index and middle metacarpals (Fig. 1–70). The angle can be measured with the back of the hand resting flat on a table. In fact, the first metacarpal cannot be placed in the reference plane because of the anteposition of the trapezium. It is understood that the definition of the position of the first metacarpal with the help of these two angular coordinates can be applied to the thumb only if the phalanges are extended in prolongation of the metacarpal.

Terms Defining the Movements. In clinical practice these movements do

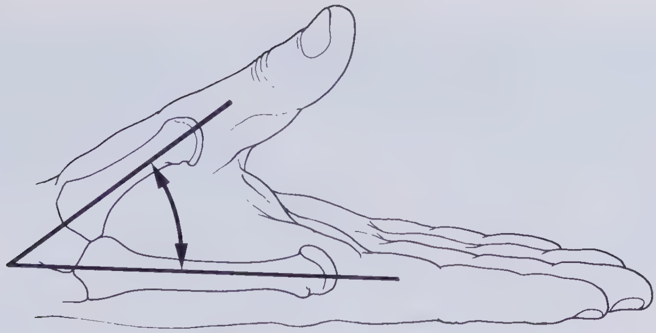


Figure 1–69. The "angle of separation" formed by the intersection of the axes of the first and second metacarpals in a sagittal plane.

not require the same precision of description, and it seems reasonable to us to continue to use a terminology indicating movements forward, backward, inward, and outward, starting from a theoretical resting position. In 1968, with Rabischong and Valentin, we proposed the use of the terms antepulsion and retropulsion to designate movements in a sagittal plane that bring the thumb into anteposition or retroposition, and the terms abduction and adduction for movements in a frontal plane (Fig. 1–71). This terminology, although somewhat inaccurate, has the merit of simplicity.

It seems to us now that the terms anteposition and retroposition are quite clear and useful. We recommend their adoption. However, the terms abduction and adduction, as well as flexion and extension, used alone, are confusing. Each time we use them we must redefine them. Instead of using them alone, we can group them in the pairs—flexion-adduction and extension-abduction.

The movement carrying the thumb ray into anteposition is accompanied by an internal rotation (pronation) of the thumb ray. The movement of the thumb ray into retroposition is accompanied by an external rotation of the

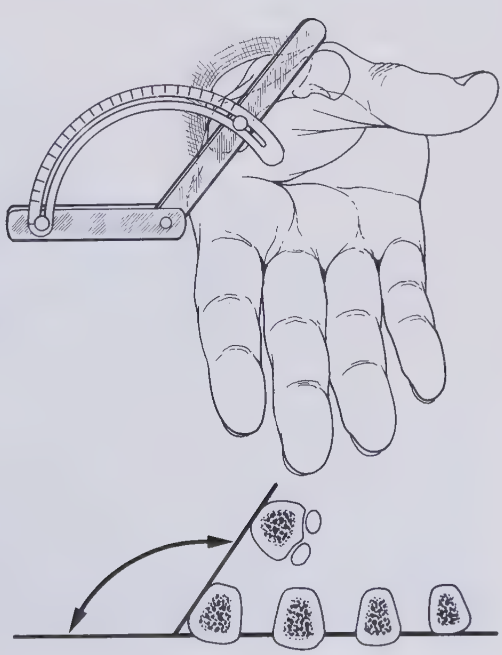


Figure 1–70. The "angle of circumduction" formed by the intersection of two planes, one passing through the second and third metacarpals and the other through the first and second.

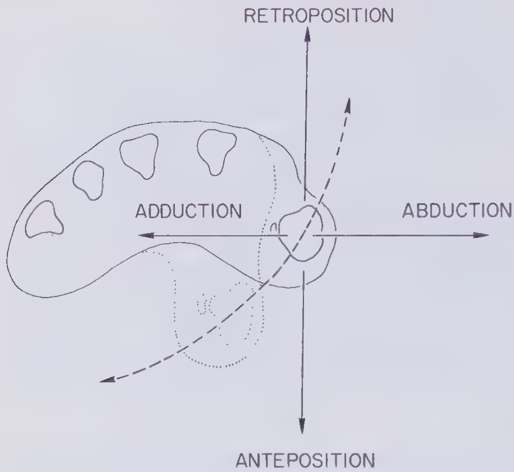


Figure 1–71. Terminology used to describe the movements of the thumb metacarpal: anteposition, retroposition, adduction (or flexion-adduction), and abduction (or extension-abduction).

thumb ray (supination). This has been described as "automatic" longitudinal rotation (Kapandji, 1972) or "conjunct rotation" (MacConaill, 1946).

Opposition is a combined movement involving all three segments of the thumb (Fig. 1–72): The metacarpal segment moves in anteposition and then in adduction, a movement that is accompanied by an "automatic" longitudinal rotation into pronation. The proximal phalanx flexes, pronates, and radially deviates. The distal phalanx flexes to a variable degree, and this flexion is accompanied by a slight pronation adapted to the requirements of the grip. There is, in fact, not one single opposition but a whole range of oppositions in a fixed conical section, as described in detail by Kapandji (1972), which allows a huge variety of grips. It is evident that the vast movement of opposition requires an expansile, mobile web space and that any retraction of the webbed area (cutaneous, muscular, tendinous, aponeurotic, or capsuloligamentous) will impair the thumb's mobility.

Figure 1–72. Opposition of the thumb is a complex movement of the entire thumb column bringing the pulp of the thumb opposite that of the fingers. It combines anteposition and adduction (or flexion-adduction) of the first metacarpal, flexion of the metacarpophalangeal and interphalangeal joints, and a global movement of rotation of all the skeletal elements into pronation.

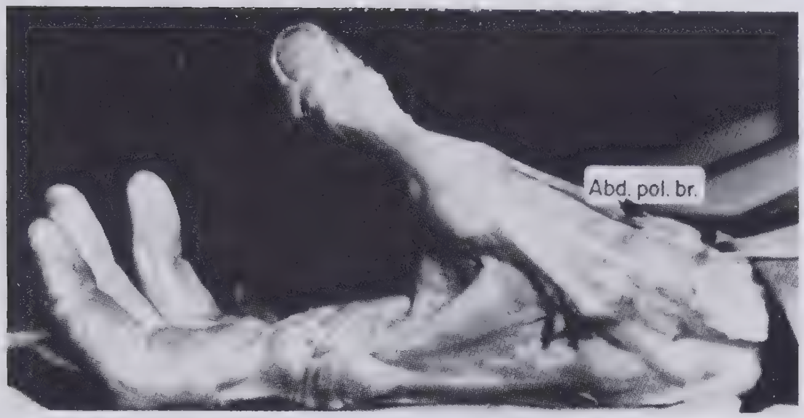


Figure 1–73. Anatomical preparation showing the lateral aspect of the thumb and first commissure; the thumb is in anteposition.

Muscles of the Thumb

The muscles that move the various articulations of the thumb ray increase in number in proportion to the planes of movement of the joints they mobilize. Their number is responsible for the increased circumference of the base of the column of the thumb (Figs. 1–73, 1–74).

These muscles, the extrinsic muscles, include the long muscles of the thumb—anteriorly, the tendon of the long flexor, which is the most powerful extrinsic thumb muscle, and posteriorly the tendons of the long abductor, the short extensor, and the long extensor. The intrinsic muscles comprise the thenar muscles, the adductor, and the first dorsal interosseous muscle and, for certain authors, the first palmar interosseous muscle (Henle, 1868). In the other digits

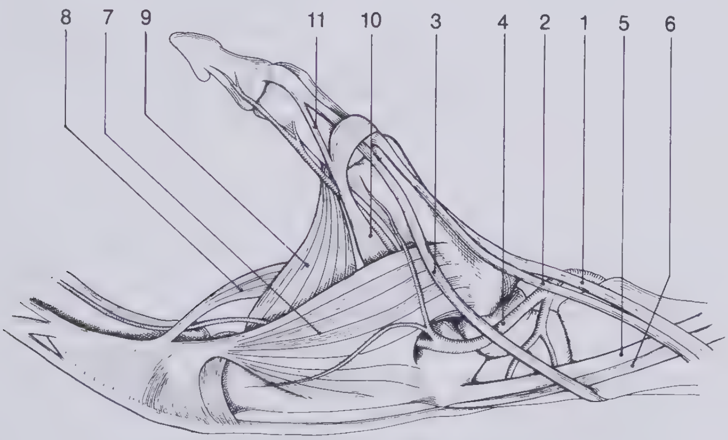


Figure 1–74. Lateral view of the thumb and first commissure with the thumb in anteposition. We can distinguish the tendons of the posterior extrinsic muscles: laterally the abductor pollicis longus (1) and the extensor pollicis brevis (2) and medially the extensor pollicis longus (3). These tendons define the anatomical snuffbox through which pass the radial artery (4) and the tendons of the extensores carpi radiales longus (5) and brevis (6). The intrinsic muscles are also shown: The first dorsal interosseous (7) inserts essentially on the base of the first phalanx; the radial side of the dorsal interosseous aponeurosis is often reinforced by the fibers of the first lumbrical (8), which is more developed than the others. Note the two components—transverse (9) and oblique (10)—of the adductor pollicis inserting on the internal sesamoid as well as on the base of the first phalanx. The adductor sends a dorsal slip (11) to the extensor apparatus, thus playing a role in extension of the distal phalanx.

Figure 1–75. Motor innervation of the thumb. The three main nerves of the upper extremity contribute to thumb movements—the radial (R) for extension and retroposition, the ulnar (C) for adduction, and the median (M) for anteposition and opposition.

(except the fifth), the total force developed by the extrinsic muscles is far greater than the forces of the intrinsic muscles, but for the thumb it is important to note that this is reversed. These muscles are innervated by the three principal nerves of the upper extremity—the radial, the median, and the ulnar—which participate jointly and successively in opposition of the thumb (Fig. 1–75). Schematically the three long posterior muscles innervated by the radial nerve open the pincer made up of the thumb and the digits, a necessary prelude to grip.

The extensor mechanism of the phalanges of the thumb is simpler than that of the digits, since there are only two instead of three phalanges. Each phalanx has a clearly defined extrinsic extensor tendon—the long and short thumb extensors. The intrinsic muscles also contribute (via the dorsal expansion of the abductor pollicis brevis and of the adductor to phalangeal extension), as in the fingers, but only for the distal phalanx. On the contrary, the thenar muscles act along with the flexor pollicis longus to flex the proximal phalanx.

The muscles responsible for opening up the first web space are the long abductor and short extensor (the extrinsic muscles) and the short abductor and opponens (the intrinsic muscles). The synergistic action of the extensor carpi ulnaris is also important in abduction of the thumb, as mentioned by Duchenne (1867). If the extensor carpi ulnaris is absent, abduction of the first metacarpal cannot be effected by will without a simultaneous movement of the hand toward the radius. The extensor pollicis longus has a unique course around Lister's tubercle, enabling it to adduct the first metacarpal and extend the phalanges. It reinforces the action of the extensor pollicis brevis on the first phalanx. It antagonizes the action of the external thenar muscles on the metacarpal but works with them in extending the distal phalanx. These functions necessitate an excursion of 5 cm., which is longer than that of the other dorsal extrinsic tendons of the thumb—the abductor pollicis longus and extensor pollicis brevis.

The thenar muscles form a cone whose summit is at the base of the proximal phalanx. They may be divided according to their distal termination into two groups: external and internal (Fig. 1–76; Cruveilhier, 1843):

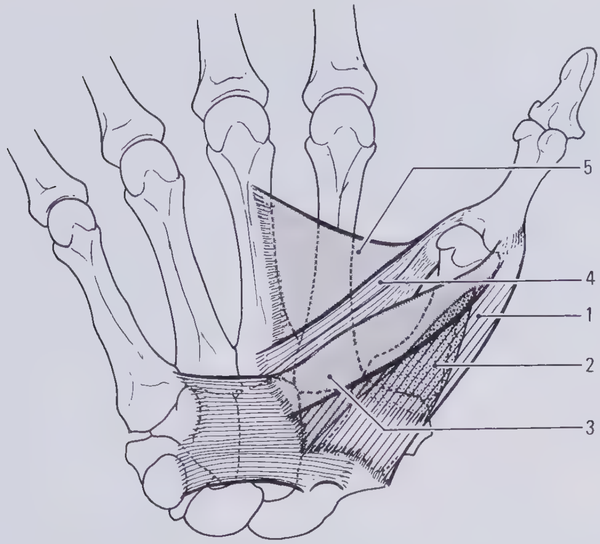


Figure 1–76. Intrinsic musculature of the thumb. On the outside are the (external) thenar muscles: (1) abductor pollicis brevis (hatched), (2) opponents pollicis (coarse stippling), and (3) flexor pollicis brevis. On the inside are the "internal thenar muscles": (4) oblique head of the adductor and (5) transverse head of adductor.

1. The external thenar (thenar proper) or external sesamoid muscles (abductor pollicis brevis, opponens, and flexor pollicis brevis), innervated by the median nerve, cause circumduction of the thumb at a distance from the palm; they are pronators.

2. The internal thenar (the oblique and transverse heads of the adductor as well as the first palmar interosseous muscle) or internal sesamoids, innervated by the ulnar nerve, bring the thumb metacarpal toward the index metacarpal, and at the end of opposition reinforce the grip. They are supinators.

As we will see, the frequent variations in the respective neural territories between the median and ulnar nerves, studied in particular by Brooks (1886), Riche (1897), Hovelacque (1927), Sunderland (1946), and Mannerfelt (1966), may have important clinical and therapeutic repercussions.

FUNCTIONAL VALUE OF THE DIGITS

Study of the skeleton and its musculature shows that each digit has an individuality and a particular functional value. The value of each digit depends on several factors, of which the most important are its strength, its mobility, and its relations with the other digits and in particular with the thumb.

In assessing the disability resulting from the loss of a digit, one must consider the possibilities of substitution of its action by neighboring digits as well as the consequences of this loss on the mechanics of the other digits and on the hand in general. The individual value of each digit must also be estimated in its relation to the hand (dominant or not) and to the occupation and hobbies of the patient. For example, the fifth digit of the nondominant hand, which finds the far note on his instrument, is of exceptional value to the violinist (Fig. 1–77).

Thumb. The thumb is the most important digit because of its mobility and force and the privileged and irreplaceable relations it has with the other digits, allowing its opposition to any one of them and to the palm. Yet one must

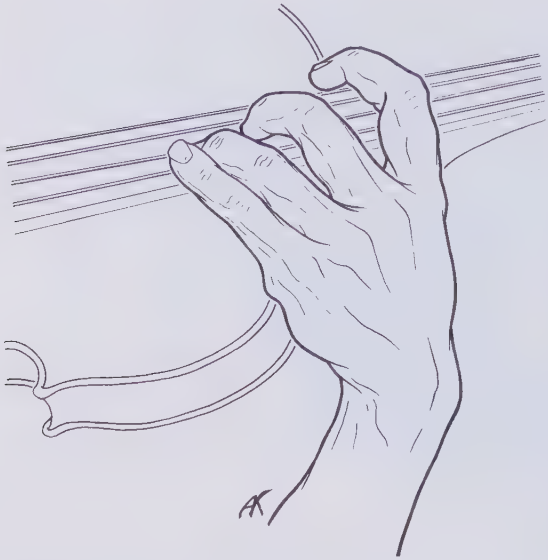


Figure 1–77. Flexion and adduction of the wrist by the flexor carpi ulnaris in the left hand of a violinist. When playing high notes, the violinist must bring his fingers up to the vicinity of the bridge by putting his wrist into flexion-adduction through the action of the flexor carpi ulnaris. When the flexor carpi ulnaris is paralyzed, as was that of the famous violinist patient of Duchenne who presented with "progressive fatty-muscular atrophy," the left hand no longer can reach the very high notes even though wrist flexion is possible through the action of the two radial wrist flexors.

remember that the exceptional functional value of the thumb comes from the mobility of its metacarpal and its intrinsic musculature, which is stronger than the extrinsic muscles. A retracted web space fixing the first metacarpal in retroposition converts a thumb with only phalangeal mobility into a particularly poorly functioning short digit.

Index Finger. The index finger is often considered the most important digit after the thumb because of its strength, its ability to abduct, the relative independence of its musculature, and especially its closeness to the thumb. This proximity enables it to play an essential role in lateral pinch as well as in distal precision handling. The deficit in power that results from amputation of the index finger is usually evaluated at about 20 per cent for digitopalmar lateral grip and supination grip. Power grip, in pronation, is considerably weakened (approximately 50 per cent [Murray et al., 1977]). In the absence of the index finger, the pronation grip of the hand lacks stability. The stability of the grip in pronation is influenced more than that in supination by the area of contact of an object with the hand. The width of the grip extends from the hypothenar eminence and the gripping ulnar fingers, which constitute the internal fulcrum, to the proximal phalanx of the index finger, which is the external fulcrum of movement. It is therefore necessary in cases of injury to the index finger to conserve the proximal phalanx when possible in manual workers.

Middle Finger. The middle finger has more strength than the index finger in flexion. It is the longest digit, and its median position enables it to participate in grips of power or grips of precision, conferring on it a great functional value. Moreover, its loss leaves the center of the hand with a defect that may produce disorders in the convergence of the neighboring digits. An amputation of the middle finger entails a greater esthetic deficit than that of the index finger.

Ring Finger. The ring finger has a strength in flexion far inferior to that of the preceding digits. It is rarely used for precision grip but participates especially in the strong digitopalmar grip, and its action is coupled with that of the fifth digit. Its loss leaves the least functional deficit of any of the fingers.

Little Finger. The fifth or little finger has the least strength in flexion because of its small size and the weak flexion strength of its distal phalanges.

However, its loss leaves a deficiency out of proportion to its small dimension. The functional importance of the fifth digit, often poorly appreciated, stems from several factors. Its peripheral position confers on it a special role in power grip. Its expansile capacity of abduction augments in effect the capacity of the hand. In digitopalmar grip the fifth digit, as the most ulnar, presses the object or the handle of the tool against the hypothenar eminence. Its viselike action is considerably reinforced by its metacarpal's ability to move forward 20 to 25 degrees, and its strength is reinforced by the powerful hypothenar muscles, which flex the first phalanx. As with the thumb, the functional value of the fifth finger can be appreciated only in association with its metacarpal. The fifth ray taken in its entirety probably has the greatest functional value after the thumb ray.

THE CUTANEOUS COVERING

The cutaneous covering of the hand has an exceptional importance because of its physical qualities, its sensory properties, and its microcirculation.

The extent of the cutaneous surface in relation to the volume of the hand is not equaled anywhere else on the body. There is a relationship comparable to that of the brain, whose surface is proportionately much larger than its total volume. The measurements reported by Morel Fatio as well as by Barreiro and Valdecasas are very close. Both found that a volume of 1 cc. in the digit corresponds to a skin surface area of 2.5 sq cm., whereas in the forearm the value drops to 0.5 sq. cm. according to Morel Fatio and to 0.4 sq. cm. according to Barreiro.

The integument of the palmar region, the back of the hand, and the web space displays a remarkable functional adaptation.

Back of the Hand (Dorsum). The skin of the back of the hand has very different characteristics from those of the palmar region: It is fine, supple, and mobile and allows the articular movements. Thus, on the right hand, the distance from the radiocarpal joint to the proximal interphalangeal joint of the middle finger is 13 cm. in extension, increasing to 17 cm. as the fist is closed and the wrist is flexed. Likewise, transversely, the distance between the lateral borders of the hand at the level of the metacarpophalangeal joints of the thumb and of the fifth finger increases from 14 to 18 cm. as the hand in the flat position closes to form a fist. Thus we can see how scar retraction or dorsal edema will limit the flexion of the metacarpophalangeal joints and the movements of the thumb.

At the distal ends of the digits the dorsal skin possesses specialized structures—the fingernails. These have lost their aggressive function as claws. Their large surface at the posterior face of the distal phalanx constitutes an external skeleton for the pulp of the finger, thus improving precision handling.

Palmar (Volar) Surface. The palmar skin, which is very thick, hairless, corneous, and inelastic, plays a role of protection and support. It is firmly attached to the fibrous skeleton and to the bone so that there is a minimum of slipping between the skeleton and the object grasped. The fixation of the skin is reinforced by the dermal insertions of the muscles—the palmaris brevis, the abductor pollicis brevis, the flexor carpi ulnaris, and the abductor digiti minimi. In the zones of grasp, the skin rests on fatty cushions, maintained by fibrous bands, and is malleable, thus adapting to the form of the objects and improving the grip. These cushions play an important functional role and are localized in front of the phalanges, in the palm in front of the metacarpal heads, in front

of the thenar eminence, and especially in front of the hypothenar eminence, which represents the tool-rest of the palm. In the central zone of the palm, on the contrary, the subcutaneous tissue is only 3 to 4 mm. thick and is subdivided by septa attaching the skin to the superficial palmar aponeurosis. The papillary ridges arranged in concentric whorls at the level of the finger tips and the glandular secretions there enhance adherence between the object and the skin. Thus the skin participates in the prehensive function of the hand. This differentiation of the palmar skin makes difficult its restoration with skin grafts from another area. However, what makes the palmar skin uniquely valuable is its richness of sensory elements.

SKIN SENSIBILITY

The hand is truly the organ of touch. The palmar skin is equipped with an enormous number of receptors of all kinds, in comparison with the skin of other parts of the body. Bossy has calculated that the lateral femoral cutaneous nerve, which has approximately the same diameter as a collateral nerve of the digits, covers a sensory territory of approximately 600 sq. cm. as opposed to 15 sq. cm. for the collateral nerve. Microscopic study of the palmar skin has shown that it possesses very specialized papillary ridges (Cauna, 1954). From superficial to deep, the sensory receptors change from free nerve endings to encapsulated receptors or "mechanoreceptors"—the Krause corpuscles at the dermoepidermal junction, the Meissner corpuscles in the dermal papillae, and the Merkel discs in the intermediate ridge. Their afferent sensory nerves consist of a high proportion of myelinated fibers. Because there are more receptors than nerve fibers, each fiber is connected to several receptors (Mountcastle, 1968).

Sensation is not of the same value throughout the palm. Certain zones are of special importance—the finger pulps, especially the ulnar half of the thumb pulp and the radial half of the index and middle finger pulps, and the radial border of the index and ulnar border of the little finger (Fig. 1–78). It is essential to maintain or restore good sensation in these regions. (For the cutaneous sensory distribution of the peripheral nerves of the upper limb, see Figure 4–62 on page 169.)

Tests of Sensibility

It is difficult to evaluate objectively the quality of sensation. We know by experience that an insensitive digit is usually not used, but what is the degree of sensation needed for function? When evaluating surgical results, it is important to distinguish between protective and functional sensation.

Omer (1973) distinguishes "sensibility" from "sensation." Sensation is the acceptance and activation of impulses in the afferent tracts of the central nervous system, whereas sensibility is the conscious appreciation and interpretation of an external stimulus producing sensation.

We all know how difficult it is to test sensibility, or rather the "sensibilities," for several reasons:

1. There are different varieties of sensibility, which are difficult to classify. The word sensibility covers everything from pathological hyperesthesia and paresthesia to the normal tactile recognition of objects (tactile gnosis) that

Figure 1–78. The functional zones of grip. In the black areas sensation is most important; in the gray areas sensation is less important.

permits prehension and work without the help of vision. Clinically, sensibilities represent heterogeneous functions of varying complexity. Some sensibilities, for example, touch, pain, temperature, kinesthesia (the perception of movement, weight, and position), and pallesthesia (the perception of vibrations), are "elementary"; they involve, in theory, specific receptors and tracts of conduction. The other, more complex sensibilities, like epicritic (discriminative) sensibility or stereognosis (perception of equilibration and orientation in space), involve an element of cortical perception.

2. The answer to tests of sensibility is subjective. "Each time we examine sensibility, we do psychology" (Dupre, 1903). The conduction velocity study for sensory nerves is the only quantitative objective technique for measuring sensation. The range of conduction velocity is 45 to 75 meters per second. The form of the action potential seems remarkably constant regardless of the nature of the stimulus (Sunderland, 1978).

3. Few of these tests have functional value. Seddon (1954) discussed the "academic" neurological tests normally used to determine sensation. Testing for tactile sensation is insufficient for evaluating functional sensation in the hand. As we shall see later, tactile sensation is just one of the sensory factors used in recognition of an object by touch or stereognosis. Moberg (1958), who has done much study on the functional sensibility of the hand, has shown that when the two point discrimination test (which is normally 3 to 5 mm. at the level of the pulps) is greater than 10 to 12 mm., cutaneous sensibility sufficient for learning and control is absent and visual control becomes necessary.

The normal values in two point discrimination tests at the different levels in the hand are presented in Table 1–3.

There are individual variations in these values depending on the thickness of the epidermis and the person's occupation.

Table 1–3. TWO POINT DISCRIMINATION IN THE HAND

Pulp of the thumb	2.5–5 mm.
Pulp of the index finger	3–5 mm.
Pulp of the other digits	4–6 mm.
Base of the palmar aspect of the digits	5–6 mm.
Thenar and hypothenar eminences	5–9 mm.
Midpalmer region	11 mm.
Dorsal aspect of the digits	6–9 mm.
Dorsal aspect of the hand	7–12 mm.

FUNCTIONAL CUTANEOUS UNITS

There are "functional cutaneous units" in the hand similar to the ones customarily described in the face. We can schematically distinguish them as follows:

Dorsum of the Hand

1. One cutaneous unit extends from the wrist to the proximal interphalangeal joints of the fingers and the interphalangeal joint of the thumb (Fig. 1–79).

2. The dorsal covering of the interphalangeal articulations of the digits forms a unique cutaneous unit characterized by a considerable excess of skin when the digits are in extension.

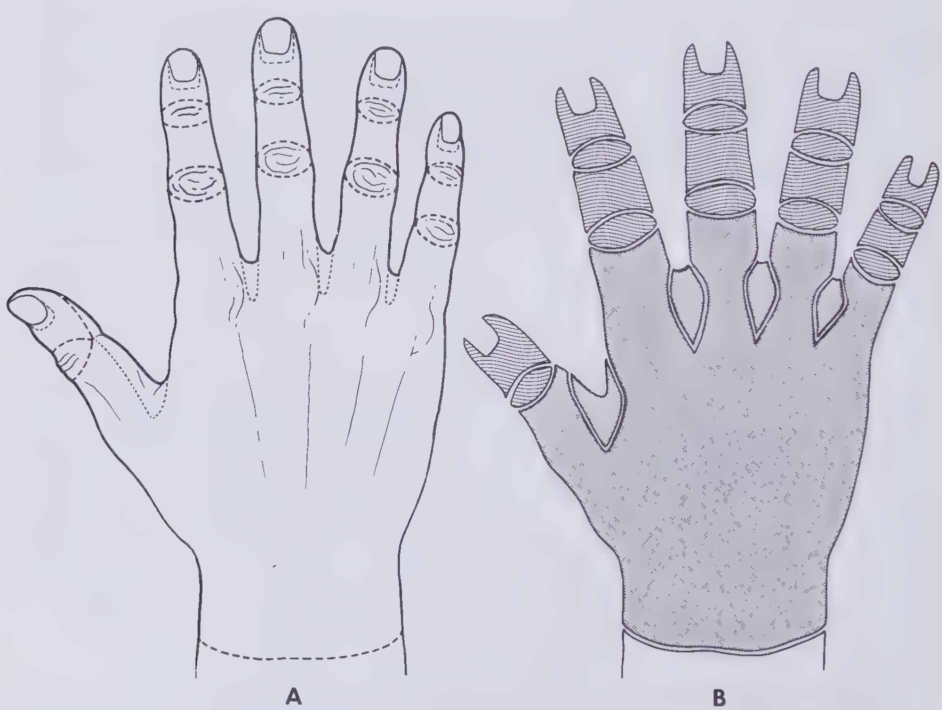


Figure 1–79. The dorsal cutaneous functional units on the dorsum of the hand and digits. In *B* the surface has been projected into a plane.

3. The fine tight skin of the dorsal aspect of the middle phalanx forms another unit.

4. The dorsal integument of the distal phalanx is very special because of the nail bed with its matrix.

Palmar Surface

The palm forms a cutaneous unit extending from the distal transverse crease of the wrist up to the transverse crease at the base of the digits. The palmar integument may be subdivided into two separate zones by the oppositional crease of the thumb, which constitutes the oblique axis of the hand (Fig. 1–80).

The skin of the radial portion, which is relatively well vascularized, covers the thenar eminence and the external part of the palm; it is the mobile portion.

The skin of the ulnar and distal portion covers the hypothenar eminence where the skin has poor mobility; the distal part of the palm beyond the transverse distal palmar crease, which is a true hinge just at the level of the metacarpophalangeal articulations; and the central triangular part of the palm, where the skin is fixed and poorly vascularized, covering almost directly the superficial palmar aponeurosis, which inserts into it.

The integument of the palmar face of the digits may be subdivided into phalangeal units. These units are separated by the digital flexion folds: three for the digits and two for the thumb. When a digit is completely flexed, the integument of the adjacent phalanges comes into contact in the zones of the flexion creases, establishing areas of cutaneous contact in the form of a diamond (Littler, 1974). The sides of this diamond do not undergo variations in length

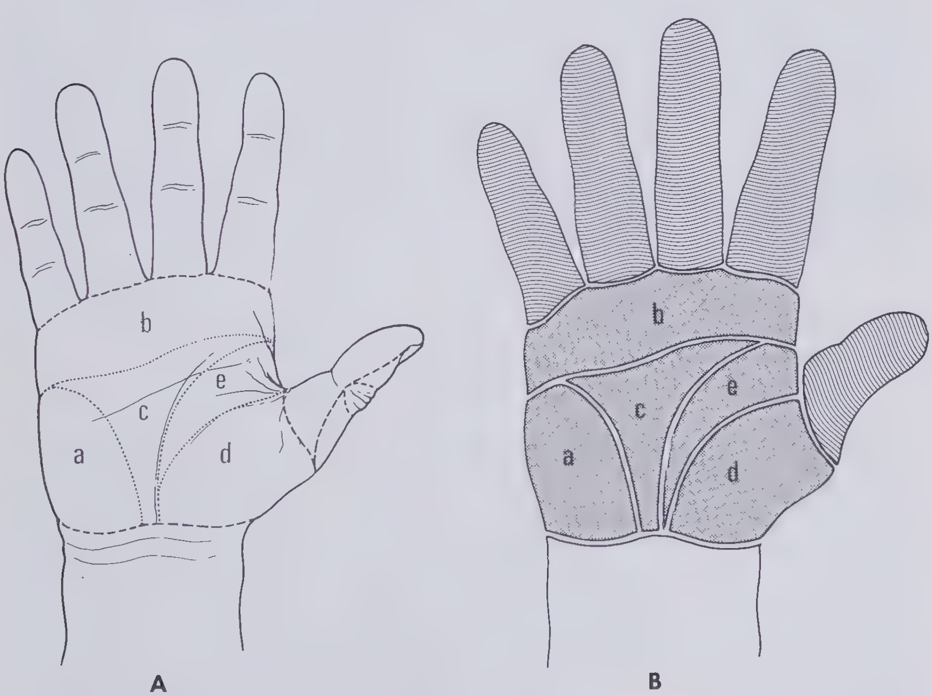


Figure 1–80. The palmar cutaneous functional units. In *B* the surface has been projected into a plane.

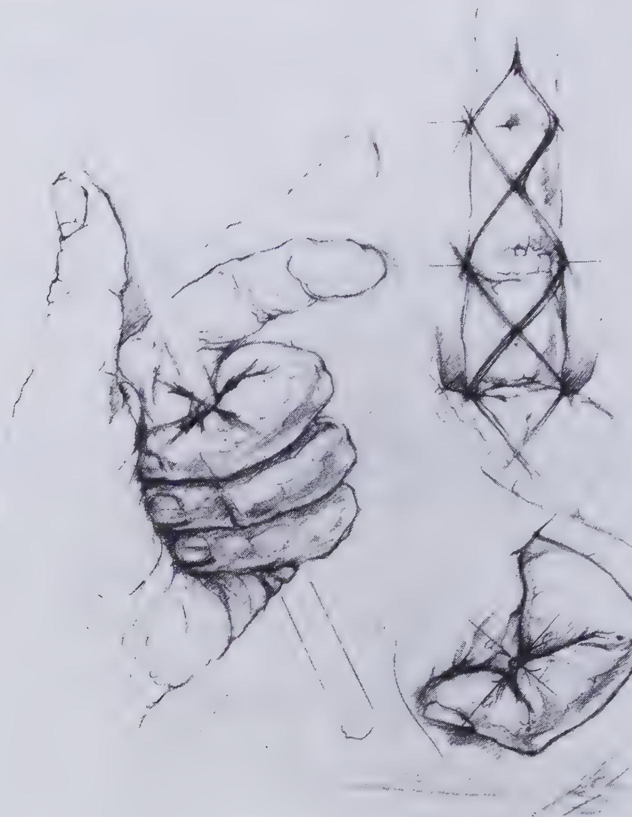


Figure 1–81. The areas of cutaneous contact in the flexed digits (Littler, 1974). These contact regions are diamond shaped when the digit is extended. The sides of the diamond undergo little variation in length during flexion-extension movements, and any incision made along their lines will not retract. When the digits are flexed against the palm, the radial digits whose palmar integument is innervated by the median nerve touch the skin of the thenar eminence, which is also innervated by the median nerve. The ulnar digits whose palmar integument is innervated by the ulnar nerve touch the skin of the palm innervated by the ulnar nerve. When a fist is formed, the palmar face of the thumb innervated by the median nerve comes into contact with the dorsal skin of the middle phalanges of the index and middle fingers, also innervated by the median nerve.

during the movements of flexion and extension, and incisions made along their level present a minimal chance of retraction (Fig. 1–81).

The palmar skin of the distal phalanges is highly specialized. The pulps are true sensory organs.

The web spaces are formed from the union of two nonsymmetrical cutaneous surfaces (Fig. 1–82). The dorsal slope has a gradual incline and its supple skin is not adherent to the subjacent region. The palmar surface is flat and precipitously interrupted, and the skin is densely adherent to the commissural skeleton. This commissural skeleton is formed by the interdigital palmar (natatory) ligament between the fingers and by the distal transverse ligament at the level of the thumb web (by far the deepest and the most mobile). Incisions must take into account the contour of these cutaneous units or of their subdivisions.

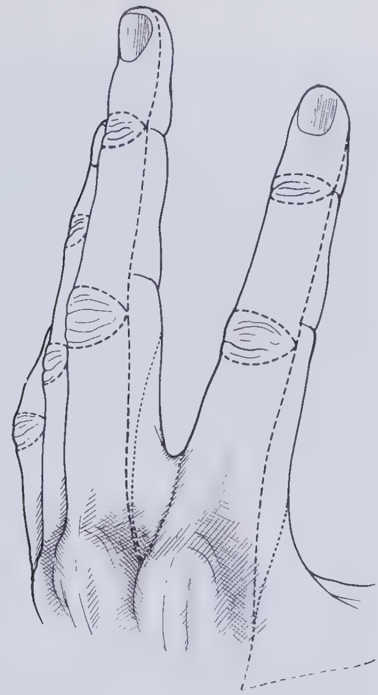


Figure 1–82. Dorsal view of the first and second commissures. The dorsum of the web slopes gently and the skin is supple and nonadherent.

As Hueston (1973) has noted, the areas of constant functional contact in the regions of each hand have a common innervation. Thus, the pulp of the radial fingers innervated by the median nerve contacts in the palm the integument of the thenar eminence innervated by the palmar cutaneous branch of the median nerve, while the ulnar or internal fingers come into contact in the palm with the skin innervated by the ulnar nerve. Likewise, the pulp of the thumb, while making a fist, closes on the dorsal surface of the distal phalanges of the middle and index fingers, coming into contact with the integument innervated by the very same median nerve.

The subcutaneous vascularization of the hand has not been sufficiently studied. Nevertheless it is of great interest for the surgeon who plans incisions and cutaneous flaps. The intracutaneous circulation cannot be studied without microdissection. The cutaneous circulation of the hand, rich in arteriovenous shunts and capillary loops, plays an important thermoregulatory role.

The Functions of the Hand

The functions of the hand are multiple, though the most important are the sensory function of touch and the function of prehension. The hand has numerous other functions that play essential roles in our lives—functions of expression through gesture, visceral functions in carrying food to the mouth, emotional and sexual functions in caressing, an aggressive function in the closed fist or the ulnar border of the hand for defense or offense, functions relating to body care, and a thermoregulatory function.

Figure 1–83. "The Hand and the Eye," by Salvador Dali. (Courtesy Museum Boymand Van Beuningen, Rotterdam.)

THE HAND AS AN ORGAN OF INFORMATION

We often have a tendency to consider only the motor functions of the hand, since this is what the surgeon most frequently endeavors to repair. However, it is impossible to dissociate sensibility and motor function in the hand; it is their association that makes the hand an important organ of information and accomplishment. What confers on the hand its exceptional sensory value is not only the great number of sensitive corpuscles of its cutaneous covering, but also the possibility of augmenting its capacity for obtaining information by means of its voluntary maneuvers of methodical exploration, i.e., by manipulation and palpation. Thus the whole of the hand is a sensory organ (Fig. 1–84). Furthermore, it is a sensory organ of particular efficiency. The other sensory organs are fixed to the axial body, whereas the hand can actively move toward an object one wants to know better. It also participates in the education of sight by correlating in three dimensions.

Let us now study briefly the mechanism of this organ of information. There are, as mentioned previously, many varieties of sensibility. These have been the subject of several classifications according to topographical site (Bell, 1833), the nature of the stimuli (Sherrington, 1896), and the hierarchy of sensibility (Head, 1920), from the elementary "protopathic" sensibility to the complex "epicritic" sensibility. Practically, neurologists classify sensibilities according to topography as either superficial or deep.

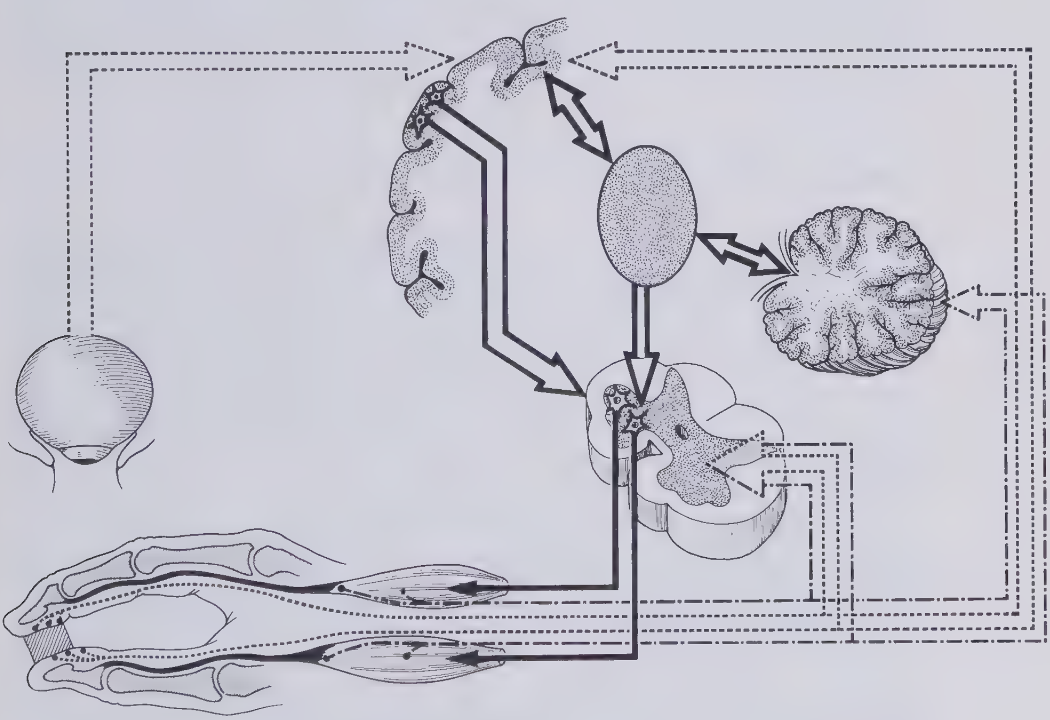


Figure 1–84. Schematic view of the sensory and motor neural pathways of the hand. The heavy lines indicate the motor pathways and the fine dotted lines, the superficial sensory or exteroceptive pathways. The dashes indicate the deep sensory or proprioceptive pathways. There are several synapses—in the medulla (1), in the cerebellum and the subcortical region (2), and in the cortical region (3)—thus permitting different medullary and subcortical reflex circuits as well as conscious control. Ocular control is necessary when sensation is absent or insufficient. The knowledge obtained from sensory input or "tactile gnosis" demands cortical participation. (After Rabischong, 1963.)

Superficial Sensation. Superficial (exteroceptive) sensation provides information regarding external stimuli of the skin receptors. It is either fine and discriminative ("epicritic") or gross ("protopathic"). It has an essential role in informing and in "discrimination of intensities or qualities and particularly of local specifications" (Head, 1920). It also has a protective role and thus brings about a regional response of defense, the most immediate and least controlled of which is the withdrawal reflex.

Deep Sensation. The deep sensation of the hand provides information regarding the position of the skeleton and muscles. Superficial and deep sensation theoretically involves separate neural pathways to the central nervous system, which decodes the information at different levels. The distinction between these two types of sensation has been increasingly criticized. It is arbitrary to equate superficial sensibility and exteroceptive sensibility; i.e., stimuli are external. It becomes incorrect when we associate deep sensibility with proprioception, in which the subject creates stimuli himself. In fact, there are proprioceptive corpuscles incorporated in and stimulated by the activity of the parts that contain them, such as bones, muscles, tendons, and joints.

Von Frey (1924) has shown that the functions classically atributed to the deep sensibilities were also assumed by superficial receptors. As he has noted, deep and superficial sensibility refers only to the topographical and anatomical locations of some receptors and does not prove the existence of any determinated functions. The skin also plays a role in proprioception. As shown by Moberg (1972), the cutaneous receptors, stimulated by deformations of the skin, play an essential role in the hand in perception of changes in position and in regulation of motor function. Thus, the cutaneous discriminative test of Weber, useful in appreciating tactile recognition, is also useful in appreciating proprioception.

"TACT" AND "TOUCH"

"Tact" is passive; "touch" is active and voluntary. Indeed the skin of the rest of the body is capable of immediately recognizing contact, but it is more often being touched than actively touching. "The hand alone can be defined as the true organ of touch," says Brun (1963), "for it alone explores or feels and thus adds to the sense of touch, activity which confers on it a unique talent. . . .Only the hand is at the same time touching and being touched." All activities of sensory investigation require the participation of motor organs. Thieffry (1973) writes:

> We are inclined to imagine that the cells of the retina, the auditory cells of the inner ear, the receptors in the skin, are themselves sufficient to give us the senses of sight, hearing and touch. Reduced to themselves, they give us only vision, hearing and tact. They only realize their full potential with the addition of sensory-motor organs which permit the adjustment to the information content that gives optimal reception.
>
> Thus, to have optimal visual perception by the retina, we must also use the oculomotor muscles of the orbit, which, by virtue of their movements, enable the eye to scan every part of the image presented. With the hand it is not only a matter of several proprioceptive receptors attached to a hidden sensory apparatus. . . . This complex sensory motor system has a greater concentration of both superficial and deep receptors than any other part of the body and this is particularly well adapted to psychomotor activity.

When the hand acts voluntarily and modifies its relations with an object to gain more information concerning this object, contact becomes touch.

Superficial sensation is precise, not diffuse, and allows "the discrimination of intensities or qualities" (Head, 1920). However, contact with a surface by digital touch is not sufficient for the precise appreciation of the weight, volume, or three dimensional size of the object examined. Palpation and manipulation add information by means of a "stereometric survey." Thus, the hand in its sensory capacity proceeds by stages to explore an object—contact, digital touch, and manual palpation. Touch and palpation together give us knowledge ("gnosis") about an object. This "tactile gnosis" provides the third dimension and educates the eye to appreciate the object's contours.

Stereognosis, a term used primarily by Hoffmann (1884) to indicate the recognition of the geometrical surfaces of an object (*stereos* in Greek means "solid"), is now used to describe the recognition of any object by touch. Stereognosis is not a function exclusively of the hands. Other parts of the body have stereognosis ability, but with many regional differences. In fact, stereognosis is the sum of partial perceptions. Perception varies from region to region. According to Delay (1935):

> Recognition of forms which is so important for stereognosis depends on spacial perceptions. Recognition of the tridimensional form needs an anatomical system allowing segmentary appreciations, done perfectly in the hands by opposition of the thumb and index [finger]. Without segmentary opposition, appreciation of volume and thickness is impossible. The influence of exercise is considerable and plays a great part in the superiority of manual stereognosis. Thus patients with infantile cerebral hemiplegia who do not exercise their paralytic hands have virtually no stereognosis. On the contrary, blind people develop a greatly increased stereognosis. In the normal adult, regions which have a limited stereognosis ability can be vastly improved by practice.

For example, after a Krukenberg operation we have observed that values in the Weber discriminative test at the distal end of the pincers progressively decrease from 4 cm. to less than 1 cm., provided the patient uses the pincers. We also know the value of sensory re-education after repairs of peripheral nerves (Wynn Parry, 1966).

In the past, touch and tactile sensibility have been regarded as the same. Slowly, progress in neurophysiology has allowed us to dissociate the different sensibilities. Touch involves the appreciation of all this information at the level of the cortex. The contribution of elementary sensibilities is indispensable to the intellectual act of recognizing an object.

In our sensory appreciation of an object we do not usually use stereognosis; we proceed by the easier and more rapid means of total symbolic perception, which precedes analysis of the characteristics of the object. This method of symbolic perception, writes Delay (1952), is "the understanding which guides us in the mental reconstruction of an object, just as in the formation of speech we progress from the idea to the phrase and from the phrase to the word." Thus we distinguish two processes in tactile recognition: immediate symbolic perception, "which is not hindered by detail," and analytic perception, which usually only supplements the fundamental information given by symbolic perception.

We see from this short account the essential role that the hands play in the recognition of the external world. Our hands work with the other sensory organs, particularly the eyes; by touch and grasping, we complete the perception of appearances. Focillon (1947) wrote:

> Perception of the world requires a sort of tactile flair. Eyesight extends along the length of the universe. The hand appreciates the reality of an object by its weight, by the texture—rough or smooth, and separates from the background with which its visual

image appears to merge. The action of the hand recognizes both intervals of space and solidity in the object it holds. Surface, volume, density and weight are not optical phenomena. It is in the hollow of the palm and between the fingers that man instantly assesses these characteristics. Space is not gauged by sight but rather by hand and foot, which impart an indefinable appreciation and without which recognition remains like a delightful landscape of a dark chamber—inconsistent, flat, elusive and chimerical.

THE HAND AS AN ORGAN OF ACCOMPLISHMENT

If we exclude walking, the majority of movements involve the hands. The upper limb has lost its locomotor function in man, except on rare occasions, and, freed by the adoption of the upright posture, the hand has become free to diversify its activities. In *The Animal Parts* (IV, 10), Aristotle wrote:

> Those who say that man is not well conceived, and that he is less well endowed than the animals, are wrong. Animals each have only one mode of defense and this they cannot change. . . . Man, by contrast, has numerous means of defense at his disposal, and it is always possible for him to change tactics and choose a different weapon when he wishes. The hand can become a claw, a fist, a horn or spear or sword or any other weapon or tool. It can be everything because it has the ability to grasp anything and hold anything.

Compared with other highly specialized organs of execution in animals, the hand is very versatile. It is both a means of expression and a variety of instruments, "a device that can, in turn, strike, receive and give, feed, take an oath, beat a musical rhythm, read for the blind, speak for the mute, reach to a friend, stop a foe, and become a hammer, pincer, alphabet. . ." (Valery, 1938).

The hand is more than just a corporal instrument. "The hand is a natural tool with the ability to fashion artificial tools" (Brun, 1963). The situation is completely different in the animal, in which the tool is an integral part of the body and "individual creativity is impossible" (Piveteau, 1955). The action of the corporal instrument of an animal is programed and is always repeated in the same manner. By contrast, "man has the liberty of his freed hands. . . . to the tool or the machine is delegated, to a greater or lesser extent, the execution of a program of concerted action" (Thieffry, 1973).

It is impossible to describe the innumerable functional adaptations of the normal hand in expressing, palpating, grasping, pushing, carrying, counting, and manipulating objects that differ widely in form, consistency, and weight. One may categorize its functions schematically according to the degree of mobility demanded of the hand:

1. The passive function, in which the hand remains immobile—flat, cupped, opened with the fingers extended for carrying, scooping, pointing, and pushing. It is the proximal part of the limb that must be mobilized to place the hand in the required position.

2. The percussive function of tapping fingers, clapping hands, or pounding fists. The distal articulations are immobile; the motion starts from the metacarpophalangeal articulations, the wrist, or more proximally.

3. Functions requiring a great deal of mobility of the hand, such as expressive gestures that are of symbolic significance, as in the language of mime, or prehensible gestures, ranging from the simplest ordinary grip to maneuvers of intricate complexity requiring collaboration between both hands.

Numerous schematic classifications of positions adopted by the fingers and thumb during prehension have been suggested, but these have tended to

describe prehension only in mechanical terms, when in fact it is a much more complex action, bringing into play consciousness, sensation, and motor function.

GRIP AND PREHENSION

In the animal world a variety of organs are adapted for prehension. According to Rabischong (1971), they may be divided into four types: organs that pinch, encircle, push, and adhere. Usually an animal can utilize only one of these forms of prehension. Man, owing to the multiple possibilities and malleability of his hands, can reproduce all types of pinch, from simple lateral pinch between two digits to thumb-finger opposition, and of encirclement, from the simple hook to digitopalmar grip. He can also use his two upper limbs for grips between the arms and the body.

Each mode of prehension in an animal is guided by a specialized system used to obtain information—the visual apparatus of a bird or the olfactory apparatus in quadrupeds, which in turn may be specially adapted, as in an elephant's trunk. Man also possesses a specific system of information and control incorporated in the hand: touch. Being able to use different types of grips, man must choose and adapt his mode of prehension not only to the object seized but also to the purpose of the grip.

To take is not simply to grasp. Like touch, prehension is intentional. This implies an awareness of utilization, and this is why prehension differs fundamentally from grip. Unfortunately there is currently much confusion between the two terms.

Prehension may be defined as all the functions that are put into play when an object is grasped by the hands—intent, permanent sensory control, and a mechanism of grip. Grip is the manual mechanical component of prehension.

Phases of Prehension

Prehension is accomplished in several stages, as described by Rabischong (1971): approach, grip, and release of grip.

Approach. Two parameters must be known in order to determine the trajectory of the hand toward an object: direction and distance. Three methods of approach are possible.

The approach via sight is the most precise; the visual apparatus immediately provides the coordinates for direction and distance. It is possible to control only one hand—not both—at a time by visual means. Visual control is essential for hand function when there is no sensibility, when the two point discrimination is more than 12 mm., or when the patient has a prosthesis (Moberg, 1978). The absence of visual control necessitates the second approach, the approach via palpation. In the third approach—via memory—the gift of memory may guide the hand toward an object.

Grip. The choice of the type of grip is preselected; the hand then adapts to the form of the object.

Grip consists of three stages: opening of the hand, closing of the digits in order to grasp the object, and finally regulation of the force of grip.

Opening of the hand requires the simultaneous action of the long extensors and intrinsic muscles. The extent is proportional to the volume of the object grasped.

Positioning of the mobile elements of the hand in order to grasp an object and adapt to its form consists of a variety of combinations.

Napier (1966) has noted that the diversity of movement of the hand is more apparent than real, if one forgets the multiplicity of grasped objects and remembers only the attitudes of the hand. The functional activities of prehension may be thus divided into power grips, in which the digits maintain the object against the palm, and precision grips, in which the palm may or may not participate. These two forms of grip depend less on the form of the object than on the reason for which the object was grasped.

Thus, when an orthopedic surgeon drives a Küntscher nail into a femur, he holds the handle of the hammer forcefully with his whole hand. The digits are flexed as tightly as possible in slight ulnar deviation; the wrist is fixed in extension, in midposition between supination and pronation, and also in slight ulnar deviation; and the thumb is adducted and rolled over the fingers to strengthen the grip and lock it (Fig. 1–85). If, however, the surgeon wants to use a chisel with precision on a bony surface, the same hammer is taken with only slight deviation of the wrist, the radial fingers are less flexed than the ulnar fingers, the index finger is in slight external rotation, and the thumb is along the axis of the handle (Fig. 1–86). The wrist, while still in midposition between supination and pronation, now has movement from radial deviation to ulnar deviation as the surgeon strikes the chisel. As the hand gains more control of an object, precision of grip is greatly increased (Fig. 1–87).

The thumb is indispensable for precision of the grip. It provides both stability and control of direction, which are necessary for precision movements. The thumb is also useful in controlling the power of the grip, forming a buttress that resists the pressure of the object that is held together by the pressure of the other fingers.

The thumb is not indispensable for all forms of power grip. Certain grips require only a simple hook formed by the fingers, which is controlled by the

Figure 1–85. In power grip the right wrist is in ulnar deviation. The adducted thumb encloses the fingers and reinforces the grip. Movement occurs at the shoulder, elbow, and wrist. The left hand grips the chisel with the wrist fixed in extension.

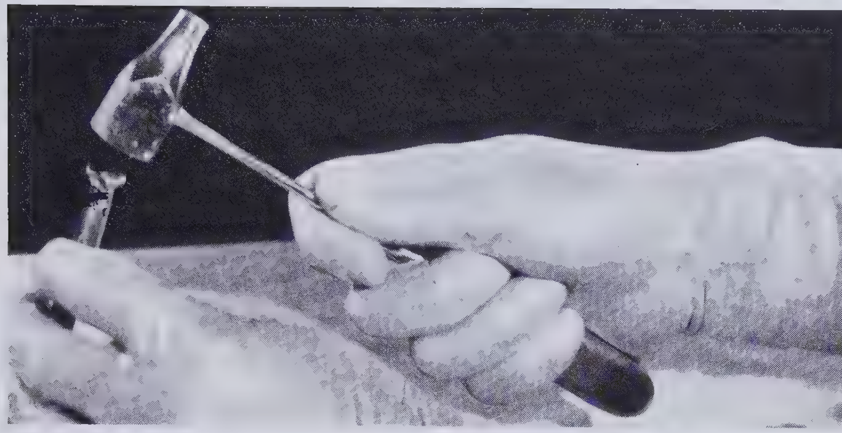


Figure 1–86. In precision grip the control of the object exerted by the hand is more extensive. The right hand holds the handle of the hammer by combining two types of grip—terminolateral grip between the thumb and the index finger and digitopalmar grip for the ulnar fingers. The thumb is in complete extension, and control of grip of the hammer extends over a wide area of the hand with more precision than that in Figure 1–85. Movements occur at the wrist. The left hand holds the chisel with precision by means of a multiple pulp grip between the fingers and the thumb.

Figure 1–87. Grip of an object along the oblique palmar axis, or palmar groove, involves a longer area of contact and thus more control than grip along the transverse palmar axis.

Figure 1–88. In digitopalmar grip, flexion movements at the metacarpophalangeal and interphalangeal joints can complement each other. In this type of hook grip the thumb is not used.

powerful digital long flexor and extensor muscles. They have more stamina than the intrinsic muscles, which control flexion of the metacarpophalangeal joints and adduction of the thumb but tire easily. Thus, with fatigue, full closure of the hand around an object is transformed into a hook of the interphalangeal joints, and precision is lost (Fig. 1–88). The intrinsic muscles assume increased importance when agility and precision are necessary; when the stress is on power, the extrinsic muscles become more important.

Landsmeer (1962) describes "precision handling," which requires continual adaptation between the thumb and the fingers without participation of the palm; this has a dynamic significance, whereas "precision grip" implies more stasis of activity.

Regulation of the force of grip is essential. The force must be varied according to the weight, fragility, surface characteristics, and utilization of the object. Precise and continuous sensory information is indispensable for safety in preventing premature release or excess pressure. The anesthetic hands of patients with Hansen's disease (leprosy), for example, have lost their capacity to receive sensory safety signals and are constantly subjected to wounds caused by excessive pressure.

Release of Grip. Opening the hand releases the grip. It is of interest that the various functions of the digits can be related to the pattern of the nerve supply. Flexion and sensation of the ulnar digits, important in the digitopalmar power grip, depend on the ulnar nerve, whereas flexion and sensation of the radial digits, important in precision grip, are controlled chiefly by the median nerve. Also the muscles of the thumb required for opposition are innervated by both the median and ulnar nerves. Opening of the hand depends on the radial nerve.

Many lesions, traumatic as well as other types, can alter prehension with all its forms of grip. We cannot hope by surgical means to restore prehension

with all its central and peripheral components. This would imply the restoration of the many sources of sensory information and control that regulate functions, the re-establishment of the numerous voluntary motor circuits at all levels of the nervous system, the reconstruction of normal muscular and articular action, as well as provision of a cutaneous covering having sensory properties. We try to make the best of the local possibilities in order to re-establish sensibility in the prehensile zones and insure a sufficient degree of mobility for the two essential forms of grip:

1. Digitoplamar grip for grasping depends on the movements of the digital joints, which can compensate for each other only partially (Fig. 1–86). Gripping large objects depends essentially on the spread of the hand and the length of the peripheral digits (see Fig. 1–88).

2. Thumb-finger pinch requires, as a minimum, active contact between the thumb and a digit, whether in opposition or in simple lateral pinch (Fig. 1–89). The size of the object gripped depends on the size of the web spaces and the lengths of the rays of the digits, especially the thumb and little finger (Fig. 1–90).

These concepts are relevant to hand reconstruction and also to prosthesis design.

NUTRITIONAL AND EXPRESSIVE FUNCTIONS

THE HAND AND THE MOUTH

Just as the hand as an organ of information is complementary to the eye, the hand as an organ of action has numerous interactions with the mouth. The act of grasping, common to both man and animals, makes use of the jaw or the hand. The hand and the mouth collaborate for the nutritional function. Placed at the extremity of the upper limb, the hand is functionally organized to take food, prepare it, and then carry it to the mouth by means of a special motion of the upper extremity—flexion of the elbow and supination of the forearm.

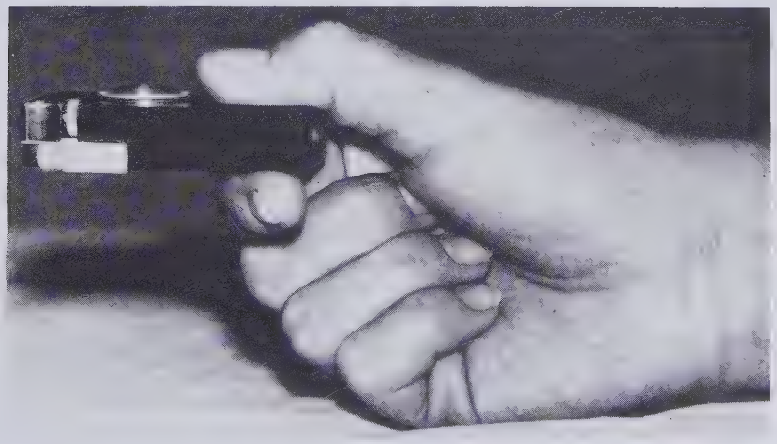


Figure 1–89. Thumb-finger grip. One of the most useful forms of this mechanism is lateral pinch between the thumb and lateral border of the index finger. This is also the easiest to reconstruct surgically.

Figure 1–90. The gripping of large objects depends on the size of the web spaces and the lengths of the digits, especially the thumb and little finger.

THE HAND AND SPEECH

The mouth and the hand have other subtle connections. After liberating themselves partially from their close nutritional collaboration, the hand became a tool and then learned how to use tools, while the mouth contributed to sounds and then to words, yet always working together. Gestures with the hand have helped shape language by contributing a rhythm, by mimicking the oratorical action. The hand, along with speech, mirrors our emotions.

Leroi-Gourhan (1967) in his work, *Gesture and Speech*, analyzed the paleontologic evolution of the motor area, including two complementary territories—the facial and the manual. As one goes up the animal scale one finds an increase in the motor area related to the activities of the mouth and the hand. These are located in the precentral gyrus. In man there is a remarkable increase in the area corresponding to the tongue, the lips, the larynx, the pharynx, the fingers, and the thumb. Eighty per cent of the motor cortex is devoted to the function of the upper limb and the mouth.

OTHER FUNCTIONS OF THE HAND

BODY CARE

Among the many functions of the hand is its role in personal hygiene. All parts of the body are accessible to each hand under normal conditions. Impairment of this upper limb function, which makes it impossible to reach the perineum or to brush the hair, makes the patient dependent upon others and has serious psychological consequences.

THE HAND AND SEXUALITY

The hand, which evolved between the oral and sexual poles, plays an important role in sexual life, especially in human contact. Caress heightens perception; the malleable hand adapts itself to the caressed form. Tetraplegic patients questioned by Moberg (1975) preferred to conserve a supple hand for human contacts rather than undergo arthrodesis, which might have made possible better motor function. It is easy to understand the frequent psychological repercussions that result from injuries to this organ, which is so essential in our relationships with others.

THERMOREGULATORY ROLE

The rich vascular network of the hand, as well as the relatively large surface of the integument, gives the hand an important thermoregulatory role. The importance is increased by the fact that usually the hands and the face are the only exposed areas of the body surface. Thermal regulation is controlled not only by the large radiation surface of the hands but also by the abundance of sweat glands. We all have experienced "sweaty palms" during times of emotional stress. This is an example of the central nervous system influence on the neurovascular regulatory role.

Physiological studies have revealed important differences in the distribution of blood between the forearm, the palm of the hand, and the digits and that the hand is greatly overperfused with regard to its metabolic needs (Burton, 1939). In the forearm 80 per cent of the blood flow is directed to muscle, a small proportion to bone, and the rest to skin. In the palm of the hand it is divided equally between muscle and skin, whereas in the digits the flow is primarily to the skin because muscle is absent. The blood flow in the digits can increase to 100 times the minimal value; the minimal value for the fingers is the value resulting during the intense vasoconstriction following exposure to cold, which is 5 to 10 ml. per min. per 100 ml. of tissue. It is estimated that less than 10 per cent of the blood flow is required for nutrition and that more than 90 per cent is required for thermoregulation (Montagna and Fellis, 1961).

One of the characteristics of the vascular system of the hand is the abundance of arteriovenous anastomoses, which, by a short-circuit mechanism, control heat loss. This mechanism is regulated by the glomus bodies, which, by opening the shunts, increase cutaneous circulation but decrease capillary perfusion.

THE HAND AND THE CENTRAL NERVOUS SYSTEM

A complex system connects the hand to the central nervous system. The richness of the sensory information and the coordination required for the numerous muscles account for the large area of cortical representation as well as all the subcortical cerebellar and pontomedullary circuits that control hand functions.

Since antiquity the relationship between the hand and the mind has been the subject of countless theories and philosophical interpretations. Evolutionists tend to regard comprehension as merely a corollary of the action of talking.

Teleologists, however, believe that nature bestowed the hand on man because he alone has the mission to build and to understand. Thus, Charles Bell, who in 1833 wrote the first treatise on anatomy of the hand, *The Hand, Its Mechanism and Vital Endowments as Evincing Design*, believed that the hand gives to the mind the power of universal domination and constitutes the proof of the existence of God.

Modern philosophers have regarded this multitalented organ as the agent of conscious activity, a distinctive characteristic of man. Focillon (1947) wrote:

> But between the mind and the hand the relationship is not so simple as that of a master to a humble servant. . . . Gestures may continually reflect the inner feelings. [Conversely,] hands have their gifts inscribed in their very shape and design—the gracile hands of the analyst, the long, fine, mobile fingers of the debater, prophetic hands exuding their fluid, spiritual hands expressing grace and character even at rest, and loving hands. The art of physiognomy, once assiduously practised by our elders, would have benefited from greater attention to the hands.

A little schematically, he concludes:

> The mind makes the hand; the hand makes the mind.

AUTOMATIC FUNCTION AND SUBLIMATION OF THE HANDS

The basic principle of economy governs the everyday activities of an organism in its relationships once the phase of sensorimotor apprenticeship is over. New connections between the preformed central nervous pathways are established, allowing automatic responses. In addition to conscious control of manual activities, control is exerted at the subconscious level; to use Moberg's comparison (1976), it is "computer control." This automatism manifests itself also in tactile perception, numbed by the monotony of routine actions, so that the grasp of familiar objects under usual circumstances becomes a stereotyped gesture. We emerge from this automatism only when something unusual occurs or a special interest draws our attention to the activities of our hands.

An almost continually conscious grasp is required in manual activities such as the artisan crafts, graphic arts, sculpture, instrumental music, and surgery in which intelligent collaboration between the brain and the hands does not allow for distraction. In certain cases we witness a true sublimation of the hand that allows it, with adequate training, to replace direct vision. It is especially true of the blind, who can read with their hands. In most religions the hand has a special symbolic significance; the laying on of hands signifies almost everywhere a pact or a blessing.

COLLABORATION OF THE TWO HANDS

The nervous system enables us to know the position of each hand at all times. In spite of a certain functional asymmetry, a cooperation or synchronism exists between the hands as well as a substitution potential that is well illustrated in amputees.

The significance of the hands has varied according to beliefs and epochs. In the Canticle of Canticles each hand has a symbolic complementary value, the left representing strictness and the right, love.

The right hand is usually dominant. Is it only the consequence of our social practices, or is it due to dominance of the left cerebral hemisphere? Does this

Figure 1–91. (Photograph by Wols. Courtesy Shirmer Mosel München Verlagsgesellschaft, Munich.)

then challenge the usual morphological symmetry for the other species of animals? It is a theme to which Bichat (1855) referred on many occasions in his *Physiological Research on Life and Death*:

> Differences of the locomotor organs are not, or almost never, natural; they are an obvious sequel of social customs, which by increasing the movements of one side, augment their skill. . . . As the habit of working perfects the action, we wrongly conclude the idea of the excess agility of the right member over the left. This remarkable difference in the two symmetrical halves of the body is thus by no means an exception to the general law of harmony of action of the external functions. . . . It is always true that this discordance is a social result and that nature from the beginning destined them for harmonious action.

One hundred fifty years later, Focillon (1947) expressed a similar view:

> The two hands are not a couple of passive identical twins. Neither are they distinguished the one more than the other like the older and the younger or like two

girls of unequal talent, one trained in many skills and the other burdened by the monotony of hard manual work. I completely disagree with the concept of the eminent dignity of the right hand. If the left fails, the right hand is placed in an almost sterile isolation. The left—this hand which is unjustly designated as the bad side, the sinister or ominous side, that side from which the dead, or an enemy or a bird should not be seen—is capable of being trained to fulfill all the tasks of the other. Constructed like the other, it has exactly the same aptitudes, which it gives up for the role of helper.

CONCLUSION

The functional architecture of the hand offers this organ multiple possibilities of adaptation, exploration, expression, and prehension. The hand joins, in the same anatomical structure, the powers of knowledge and action. It is both the origin of very precise information and the irreplaceable executor of the wishes of the brain. The hand is the privileged messenger of thought.

The more we study the hand, the more we marvel at its extraordinary efficiency and the wealth of pathways that connect it to the central nervous system. However, this subtle organ, whose mechanisms we have not yet fully understood, is by necessity exposed and complex. It may be threatened or destroyed by many traumatic or pathological processes.

ACKNOWLEDGMENTS

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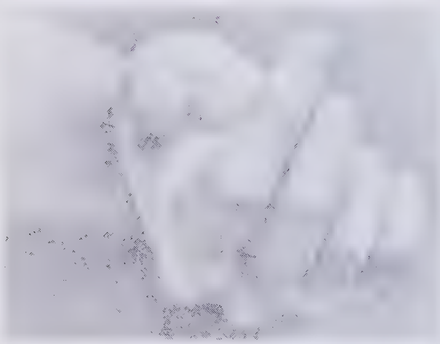
CHAPTER TWO



THE SKIN OF THE HAND

The skin covering the hand is more important physiologically and pathologically than that at any other site on the body. Indeed, its characteristics cannot be dissociated from the motor and sensory properties of the hand. Morever, there is an evident difference between the palmar and dorsal skin: both anatomically and functionally they are different from and independent of each other. The dorsal skin, which is fine and supple, working only on tension, is not used as a resting or sensory surface, and its chief virtue is that it does not impede free articular mobility in flexion. By contrast, the palmar skin is thick, tough, and resistant to pressure; it stabilizes the grip and, particularly at the pulps, has important sensory functions.

THE PALMAR SKIN

HISTOLOGICAL STRUCTURE

The histological architecture of the palmar skin is similar to that of skin elsewhere, but it has additional features that are functionally relevant.

The Epidermis

The epidermis is made up of four elastic layers in addition to the stratum lucidum (Fig. 2–1). Starting with the deepest and moving superficially, they are as follows:

The Basal Layer. The basal layer consists of a unicellular stratum of basal cells mingled with melanocytes. Cell multiplication occurs during periods of skin regeneration. Its deep aspect rests on the basement membrane, a fine acellular structure marking the dermoepidermal junction, to which it is attached by means of protoplasmic prolongations known as hemidesmosomes. The basement membrane itself is anchored to the superficial layer of the dermis by collagen or retinacular fibrils, which indirectly "fasten" the dermis to the epidermis.

The Malpighian Layer. The malpighian layer (or malpighian body) consists of a thick multicellular layer of polygonal cells that become flatter as they

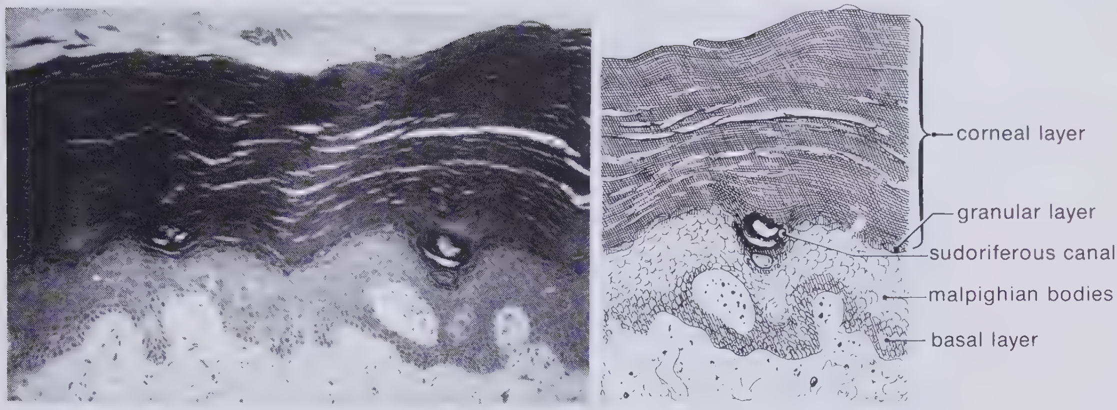


Figure 2–1. Section of palmar skin showing the layers of the epidermis. Note the multiple levels of the exocrine gland ducts and their spiral course.

approach the surface. They are united by intercellular bridges or desmosomes. As with the cells of the basal layer, their cytoplasm is rich in tonofibrils made up of a keratin precursor. This layer is also a site of cellular multiplication and plays a significant part in skin regeneration.

The Granular Layer. The granular layer is two to three cells thick, and its thickness is further enhanced by active keratinization. The cells take the shape of flattened lozenges and contain numerous cytoplasmic granules of the lipoproteinaceous substance, keratohyalin.

The Horny Layer. The horny layer (stratum corneum) is made up of flattened cells transformed by keratinization with no detectable intercellular spaces; they are recognizable at the light microscopic level by the absence of nuclei or only vestigial nuclei (Fig. 2–2).

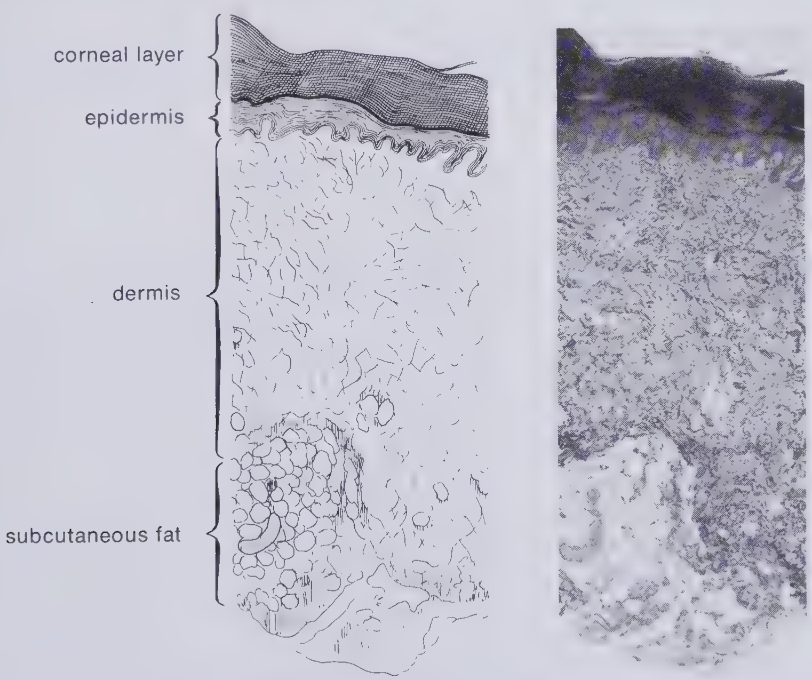


Figure 2–2. Section of palmar skin demonstrating the thickness of the horny layer in relation to the epidermis as well as the thickness and density of the dermis.

The Stratum Lucidum. The stratum lucidum, situated between the granular and horny layers, is a feature of palmar and plantar skin. It is two or three cells thick, and the cells are flattened, anuclear, homogeneous, translucid, and rich in an oily substance, eleidin.

The Dermis

The dermis is a connective tissue whose structure is an intertwining of collagen, elastic, and reticular fibers. Within this fibrillar network are scattered a few cells, together with blood vessels and nerve endings.

The Superficial Layer. The superficial layer is in close contact with the epidermis. On section, the irregular junction line is characterized by alternating dermal protrusions (dermal papillae or papillary ridges) and epidermal protrusions (the epidermal ridges). This type of dermis therefore is known as papillary dermis.

In the superficial papillary zone, the connective fibers form a meshwork, and these fibers tend to follow the axis of the papillae. As we have seen, the reticular fibers, together with the elastic fibers, anchor the epidermis to the dermis. Vascularization here consists of capillaries arising from superficial plexuses and following the axis of the papillae. Sensory nerve endings found in this layer are primarily Merkel's subepidermal discs and the intrapapillary Meissner corpuscles.

The Reticular Dermis. In a deeper plane lies the reticular dermis. The collagen fibers are thicker and more abundant, and the numerous elastic fibers form an undulating pattern. The orientation of the fibers is mostly in a line parallel to the surface of the skin. Running up from the deeper layers are the fibrous cones, bundles of collagen fibers that unite the dermis to the underlying fascial planes and through which run the vessels and nerves from the subcutaneous layer.

The superficial vascular plexus lies between the superficial and middle layers of the dermis, whereas the deep plexus lies between the dermis and subcutaneous cellular tissue.

Characteristic Features of the Palmar Skin

The Papillary Structure. The junction line between the palmar dermis and epidermis, characterized by alternating dermal and epidermal ridges, indicates that the palmar skin is of the papillary type. The papillary ridges, far from being erased by the superficial epidermis, are actually enhanced, especially by the horny layer. The dermis is said to be delomorphic, its macroscopic relief appearing superficially as ridges that contribute to the dermatoglyphic patterns. The pores of the sweat glands open at the "summits" of these ridges.

Meissner's corpuscles, the mediators of touch, also are found in the dermal papillae. This arrangement enables them to register pressure exerted perpendicular to the skin and transmitted through the overlying epidermis. Because of the epidermal ridges situated on the lateral borders of the papillae, Meissner's corpuscles also can register lateral pressure exerted parallel to the plane of the skin and originating in stimuli applied at a distance from the corpuscle concerned (Fig. 2–3). This arrangement contributes to the accuracy of the sense of touch.

Mechanical Resistance. Mechanical resistance is a highly important physical feature of skin. It is the result primarily of a particularly thick middle dermis,

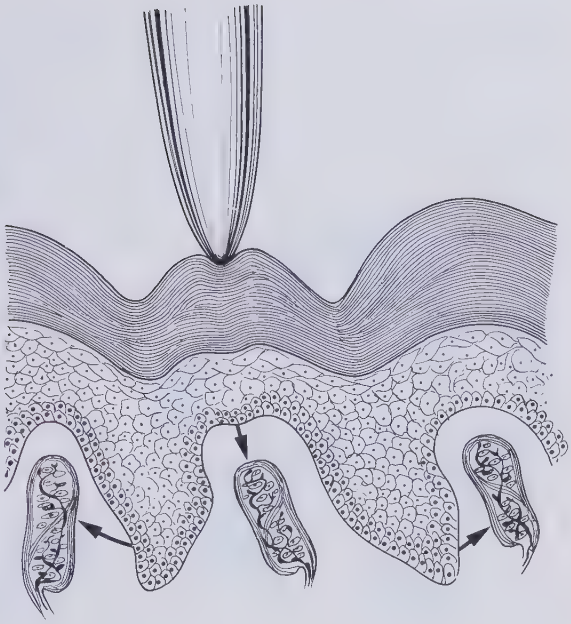


Figure 2–3. Role of the epidermal ridges in the stimulation of Meissner's corpuscles. The lateral resultant of vertical pressure on a papilla and the corpuscle contained therein also stimulates the corpuscles of the adjacent papillae. (After Cauna, M.: Nature and functions of the papillary ridges of the digital skin. Anat. Rec., *119*:449, 1954.)

which is itself securely anchored to the deeper planes by the fibrous cones. It is reinforced by the thickness of the epidermis, all of whose layers show signs of activity. One of the most important factors is the thick horny layer, which has some unusual structural and physiological features.

The Horny Layer. In the hand the thickness of the horny layer ranges from 0.5 to 2 mm. compared with 0.02 mm. in other areas. The horny layer is made up of a thick layer of cells whose framework remains visible; this is the site of type A keratinization and contains a filamentous network that presumably favors hydration. The important horny layer can be replaced in its entirety within 20 days without the appearance of a "stratum desquamante" visible elsewhere in the skin.

The horny layer has a high hydration potential, which increases its thickness and contributes to its strength and suppleness. This imbibition is maintained by a lipid surface film, which, in the absence of the sebaceous system, originates in the lipids eliminated from the superficial cells. The hydration source is twofold—insensible perspiration as elsewhere in the body and a special arrangement of the sweating system.

The Cutaneous Adnexa. The palm does not possess a pilosebaceous system, but it has an abundance of exocrine sweat glands (2600 per square inch). These are characterized by unusually long excretory channels by reason of the thickness of the skin and horny layer and also because they run a spiral course through the epidermis. This arrangement, which facilitates imbibition in the horny layer, is also responsible for the complications of hyperhydrosis.

Physiologically true, visible perspiration of thermal origin is relatively poor in normal subjects, but it can be modified by various factors (e.g., emotion, pain, smoking). Palmar sweating takes the form of almost continuous insensible secretion, although individual glands show sporadic activity, which alternates with that of their neighbors. This insensible perspiration, which is probably absorbed before it reaches the surface, maintains the hydration of the horny layer.

A B

Figure 2–4. *A*, Palmar print taken from a cylindrical tool handle (diameter, 4.4 cm.). Note the predominance of pulp prints, especially of the cubital fingers locking the grip, and of the hypothenar eminence. *B*, Palmar print, hand flat. Note the concentric arrangement of the pulp prints and the hypothenar print and the transverse organization of the striae on the distal part of the palm. Note also Lange's lines, which form fine longitudinal or transverse striations.

We recall that the pores open at the crest of the epidermal ridges and aid in maintaining their moistening and suppleness. In this indirect way the sweating mechanism plays a part in promoting sensation.

MACROSCOPIC APPEARANCE

The palm of the hand is characterized by a system of cutaneous folds, which are present from birth and have physiological significance.

Fingerprints

The cutaneous striations that make up the fingerprints form the essential part of dermatoglyphics (Fig. 2–4). They reflect the arrangement of the papillary ridges of the underlying dermis whose outline is enhanced by the thickness of the stratum corneum.

Their specific distribution over the pulps is of well known medicolegal importance, but they are in fact present all over the palmar skin. Their overall orientation is predominantly transverse; at the pulps they form a typical concentric pattern, whereas in the midpalmar area they tend to run longitudinally and obliquely.

These striae are particularly well developed in cutaneous areas involved in the grasping of objects, and conversely they are much less evident in skin areas not usually concerned with prehension. They are particularly in evidence, therefore, on the ulnar aspect of the distal phalanx of the thumb and radial

border of the three ulnar fingers. They are also prominent in the skin covering the proximal part of the hypothenar eminence, which is important in the grasping of tool handles.

These striae play an important part in the retention of an object during the act of gripping by preventing it from sliding over the skin. The concentric arrangement of the striae at the pulp ensures the presence of a group of striae perpendicular to the force exerted, whatever its direction. Finally, they have a tactile function by reason of the distribution of Meissner's corpuscles (vide supra).

The Skin Creases

On the palmar aspect of the hand is a system composed primarily of transverse creases whose configuration forms the basis of palmistry, or chiromancy. With the exception of the so-called opposition crease, which forms the boundary of the thenar eminence, these creases correspond to the lines along which the skin is folded when the hand is closed; hence the name, flexion creases. In the fingers the flexion creases indicate a line of adherence between skin and fascia with no intervening adipose tissue. In the palm the proximal and distal palmar creases mark the dermal terminations of numerous longitudinal fibers of the palmar fascia. The opposition crease of the thumb coincides with the lateral border of the central fascial triangle of the palm; it marks the boundary between the fixed central palmar skin and the mobile thenar skin that moves with the column of the thumb.

The palmar creases, which are often used as landmarks, do not in fact overlie the joints whose flexion induces them to fold (Fig. 2–5). Only the

Figure 2–5. Projection of cutaneous folds in relation to the skeleton.

middle digital creases coincide with the proximal interphalangeal joints; the distal crease lies just distal to the distal interphalangeal joint, and the proximal crease lies almost halfway down the proximal phalanx.

In the palm the distal palmar crease, which lies in the ulnar half, runs just proximal to the medial metacarpophalangeal joint lines; the more radial proximal crease lies well above these joints.

Lange's Lines

As in other zones of mobile skin, the hand shows a fine system of lines of tension, independent of the skin creases, which correspond to Lange's lines.

RELATIONS BETWEEN THE SKIN AND DEEPER PLANES: THE PALMAR FAT PADS

Unlike its dorsal counterpart, the palmar skin is anchored to the underlying fascial planes by a system of fibrous tracts. As we have seen, this union results from close approximation along the lines of cutaneous stasis. The skin also adheres closely to the aponeurosis in the midpalmar area, a triangle whose boundaries are the opposition crease of the thumb, the lateral border of the hypothenar eminence, and distally the two transverse palmar creases.

In all other areas, the deep aspect of the skin is separated from the superficial palmar fascia by a layer of fatty tissue, which is itself divided into compartments by the fibrous septa already mentioned. The result is a system of fat pads, which are malleable even though they are tethered to the skin above and the aponeurotic plane below (Fig. 2–6). Three such pads or cushions are recognizable:

1. The thenar pad lines only that part of the thenar eminence nearest the palm; the proximal and lateral parts of the thenar region are almost fat-free.

2. The hypothenar pad is broader and thicker; it lines the hypothenar

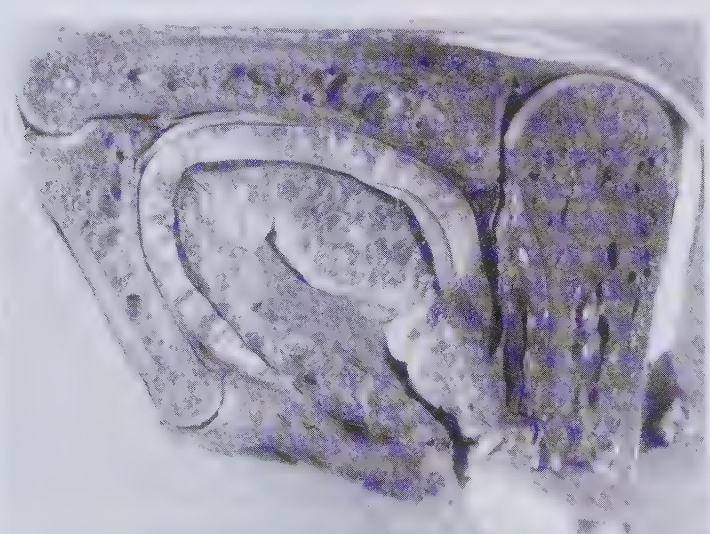


Figure 2–6. Section of the hand and finger showing the subcutaneous palmar fat pads. One can see the metacarpophalangeal and phalangeal pads whose structure is similar to that of the pulp, allowing the finger to mold its palmar surface to the object to be gripped.

muscles and spills over the ulnar border of the hand, giving it its rounded outline. Proximally the two pads are connected by an adipose band, which stretches in front of the flexor retinaculum.

3. The metacarpophalangeal pad sits transversely over the base of the fingers from the ulnar to the radial border of the hand. It is thicker over the interdigital spaces than over the flexor tendons and is bounded proximally by the transverse palmar creases. Distally it lines the interdigital palmar ligament at the commissure but is absent under the proximal digital flexion creases.

Each phalanx presents a similar system of fat pads between the digital flexion creases. The pulp also has its lobulated palmar pad, but here the fibrous septa join the periosteum of the distal phalanx to the deep aspect of the dermis.

These pads have great functional significance, because they are essential to prehension. The lobulated structure under a tough dermis, an arrangement similar to that found in the plantar pads of quadrupeds, provides cushion-like resistance to pressure. In addition, their malleability enables the hand to mold itself around objects without the skeleton's being directly involved. They increase the surface available for contact and thus improve retention during grip.

The most characteristic feature of palmar skin is its tethering to the deeper planes. This is achieved by direct adherence at the lines of stasis and by the fibrous septa that cross the fat pads. This fixation prevents the skin from gliding over the underlying tissues and allows direct transmission of the gripping effort without any risk of skidding. It makes an important contribution to the stability of the grip. The palmaris brevis, which tethers the hypothenar skin to the deeper planes, can be regarded as a complement of this system of cutaneous stabilization.*

THE DORSAL SKIN

HISTOLOGICAL STRUCTURE

The histological features of the dorsal skin are not unlike those of its palmar counterpart. It has a papillary dermis, but the papillary ridges do not show on the surface because they are neutralized by the epidermis (adelomorphic dermis). The latter is thin and is lined by a horny layer that is only 0.02 mm. thick.

The dermis is also thinner and less resistant; it has only loose connections with the deeper planes, over which it can move freely. Unlike the palm, however, it possesses a normal pilosebaceous system.

Finally, owing to the thinness of the epidermis and the dearth of connective and elastic tissue elements in the dermis, the dorsal skin becomes fragile in old age and has a greater vulnerability to factors causing cutaneous atrophy, such as steroid therapy.

SKIN MOBILITY

The dorsal skin owes its suppleness and mobility to its histological structure. Its relative thinness makes it more stretchable, and its loose connections with

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*The palmaris longus, flexor carpi ulnaris, and abductor pollicis brevis act similarly through their skin insertions.

the deeper planes allow free gliding and full flexion at the digital joints. Indeed, flexion of the fingers produces a significant lengthening of the dorsal skin. Thus, in the middle finger, the distance between the wrist and the ungual fold shows an average increase of 3 cm. as the finger goes from extension to full flexion (range, 2.1 to 3.6 cm.). Flexion at the metacarpophalangeal joint alone requires an average skin lengthening of 1.25 cm. (range, 1 to 2 cm.). The gain in length does not occur solely at the metacarpophalangeal skin; a variable but significant gain occurs as a result of gliding and stretching over the hand and wrist.

This mobility is the result in large part of the loose arrangement of the subcutaneous cellular tissue. When this tissue is distended by edema, the stretching and gliding are considerably reduced during flexion; hence, the posture in extension of the metacarpophalangeal joints in edema of the hand.

Flexion of the proximal interphalangeal joint may occur at the expense of the segment of loose skin immediately above the joint, while proximally and distally the integument is more strongly anchored to the digital fascia. This segment is well delineated by deep dorsal creases and can on its own provide a gain in length that is fairly constant, between 0.7 and 0.9 cm.

THE DORSOPALMAR SEPTA

The dorsal and palmar areas of skin are independent because of a system of adhesions that anchors their common boundary to the underlying plane. This anchoring is well marked on the ulnar border of the palm and even more so at the lateral borders of the fingers.

In the proximal part of the first phalanx, fixation occurs almost in a straight line in the plane of the commissural crest: it takes the form of small fibrils arranged in the shape of a fan that unite the deep aspect of the skin and the digital fascia.

More distally, and especially opposite the middle and distal phalanges, the adhesion band is more tightly packed and lies just posterior to the palmar collateral neurovascular bundle on the lateral side. It corresponds to the reinforcement in the digital fascia known as the digital band and to the point of attachment of the osteocutaneous ligaments. These deep attachments stabilize the skin in relation to the skeleton and prevent the integument from sliding freely over the motor system like the finger of a glove.

BLOOD SUPPLY OF THE SKIN OF THE HAND

In general terms we can say that the skin is supplied by both a deep and a superficial plexus. The deep plexus, which lies between the dermis and the subcutaneous tissue, consists of arterioles with three-layered walls (adventitia, media, and intima), the outer layers becoming progressively thinner as the vessels cross the dermis and approach the surface.

The superficial plexus is essentially subpapillary. The papillary capillaries to which it gives rise are lined by a single layer of endothelial cells, but at various points on its course, the capillary tube is surrounded by contractile cells (and their processes), the pericytes.

The cutaneous circulation of the hand has special anatomical and physiological features that are related to its distal situation (i.e, far from the cardiac impulse) and to its constant exposure to thermal and postural variations.

THE ARTERIOVENOUS CIRCUIT

The general pattern is not different from that found elsewhere—muscular arteries running into arterioles, capillary meta-arterioles with precapillary sphincters regulating the blood flow, and the return through the venous loops.

In the hand, however, the circuit in addition contains a system of shunts between the arterioles, meta-arterioles, and venules as well as more specific structures found mostly in the palm, near the roots of the nails, and in the pulps. These are direct arteriovenous anastomoses known as Sucquet-Hoyer anastomoses. They consist of spiral vessels that run from the hypodermis to the superficial plexus; on the way the artery loses its elastic fibers and its epithelium becomes more cuboid. The muscle wall thickens and takes on a sheath of epithelium-like cells (regarded by some as muscle cells), and the whole become sheathed by a network of nonmyelinated nerve fibers. This is the complex known as glomus tissue (Fig. 2–7). At the summit of the glomus body the arteriole becomes thinner as it enters the subpapillary plexus. This interesting shunt system appears to play a part in local heat regulation.

CAPILLARY CIRCULATION

A remarkable feature of the circulatory system in the hand is the great density of capillaries—64 capillary loops per sq. cm on the dorsum of the hand compared with 16 at the cheek and 44 papillary capillaries per sq. cm. of skin on the hand compared with 27 at the shoulder and 19 at the cheek.

The variation in capillary pressure, which exists in the skin elsewhere, is much more marked in the hand. The variation is noticeable from one moment to another at one point, and at the same moment at any two points of the network.

The variations in blood flow are no less remarkable. These can be visualized by capillaroscopy at the base of the nail where the capillaries of the papillae run horizontally and parallel to the surface. The loop can be seen in its entirety. In certain conditions one may observe some degree of sludging; this phenomenon also can be seen with a reduction of capillary pressure or in the presence of local changes, e.g., in the endothelium or the protein film.

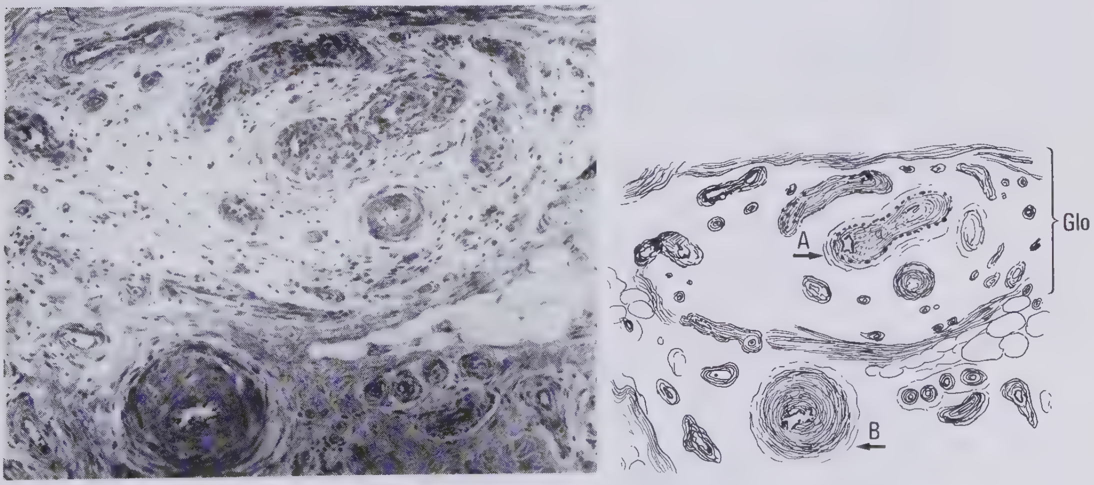

Figure 2–7. Section of Masson's glomus. A, Capillary surrounded by a casing of glomus cells. B, Afferent arteriole with muscular wall.

Capillary pressure itself depends on a number of factors, such as arteriolar tone (arteriolar constriction increases peripheral resistance and reduces capillary pressure), venous return (increased venous pressure causes an increase in capillary pressure), the position of the hand (pressure can decrease from 40 to 4 cm. as the hand is raised from the dependent position), and temperature.

It is important to notice that the rate of blood flow is highly variable in the distal extremities where arterial irrigation is most marked. This feature has been studied in the fingers and especially in the pulps, where photoelectric plethysmography has shown that the flow can vary between 0.5 and 100 cc. per 100 cc. of tissue, or by a factor of 200:1. There is little doubt that this variation is due to the presence of numerous direct anastomoses.

REGULATION OF CIRCULATION

All these observations emphasize the importance of the system of autonomous regulation that prevails in the skin everywhere, especially in the extremities and the hands. It is responsible for the maintenance of adequate muscle tone in the arteriocapillary network.

This regulator mechanism receives sympathetic discharges of central (hypothalamic) origin every 30 to 40 seconds, resulting in the liberation of norepinephrine at the extremities. Regulation is not under voluntary control but is activated by various factors acting through the so-called long axon reflexes. These include pain, emotion, forced inspiration, and smoking, which chiefly influence the distal circulation, probably because of the presence there of numerous arteriovenous anastomoses.

It is generally accepted that vascular tone is reduced during sleep, and this factor would explain the vasodilation normally observed in the hands and feet during that period.

Inhibition of this mechanism under certain conditions can induce antidromic vasodilation (i.e., transmitted against the direction of flow of the normal nerve impulse). This response, which is the reverse of the previous one, has a slow onset (20 to 40 second lag), lasts for 5 to 10 minutes, and appears to be mediated by acetylcholine.

This mechanism is reminiscent of the short-axon reflex, which is also antidromic and induces vasodilation as a result of local stimulation. It is probably important in hand disease. Indeed this type of reflex and its persistence have been incriminated in the spread of causalgia, which is sometimes seen after injury to the peripheral nerves, especially the median nerve.

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CHAPTER THREE

CLINICAL EXAMINATION OF THE HAND

The clinical examination of the hand should have two primary objectives—to detect and assess lesions as accurately as possible (the choice of treatment will be based on this assessment) and to evaluate the adequacy of remaining functions. On this evaluation will depend the decision to operate and the quantification of incapacity. However, function can be appreciated only in the light of other factors, such as the condition of the rest of the limb and that of the contralateral hand and the patient's professional background, which in turn will determine the manual requirements and influence the potential for recovery.

It is probably fair to say that the clinical examination is by far the most important source of information. Radiological, electrical, and thermographic examinations supply complementary information limited to certain structures, but only through the clinical examination can the state of the skin, joints, tendons, and aponeuroses be properly assessed. The same applies, of course, to manual function.

In the injured hand with its precarious blood supply, two ancillary investigations are available: thermography, which provides information about overall metabolism, and arteriography, by which named and unnamed arteries and veins are visualized.

The clinical examination of the hand involves a series of specific examinations to appraise the skin cover, circulation, trophic changes and sweating, bones and joints, muscles and tendons, the overall motor performance of the hand, tactile sensibility, and deep sensibility.

THE SKIN COVER

CHARACTERISTICS OF NORMAL SKIN

Thickness and suppleness are assessed by noting callosities on the pressure areas and the thickness of the skin folds, keeping in mind that connections to the deeper planes are normally present in several areas. It is thus possible to distinguish between hands with supple skin and normal mobility and those with thicker skin and reduced passive mobility. From a practical point of view, the three main implications are that the thick, callused skin of the manual laborer

requires more thorough preoperative preparation; that plastic repair is much less likely to succeed on thickened, less mobile skin; and that the thickness of the epidermis and the horny layer must be taken into account in testing cutaneous sensation.

The availability of skin must be assessed prior to all plastic repairs and mobilizing operations, especially in areas that are usually mobile, e.g., the dorsal aspect of the interphalangeal and metacarpophalangeal joints, the dorsal aspect and crest of the first web space, the dorsal aspect of the phalanges (if one intends to perform a Z-plasty on the palmar aspect of the finger), and the dorsal aspect of the hand.

Signs of skin atrophy must be searched for in patients in whom long term corticosteroid therapy has been prescribed and those with neurovascular problems. Atrophied skin has about the same appearance as the skin in senile cutaneous degeneration. It has a shiny appearance, a thinning of the dermis and epidermis, and a loss of elasticity. Reduced thickness and persistence of the skin creases are the characteristic signs. The presence of stellate pseudoscars is a typical change. These alterations limit the scope of plastic repairs and are usually associated with poor skin healing.

SCARS

Careful scrutiny of all scars is an essential part of the examination of the skin. Scars can be one of the factors responsible for reducing the mobility of joints and must be taken into account in testing articular mobility. The most common are longitudinal palmar scars that run across the flexion creases; contracture of these scars interferes with extension of the fingers. Dorsal scars, especially where they create adhesions, may reduce the mobility and extensibility of the skin, even in the absence of contracture. Flexion is then affected. Web space scars, by invading the palmar interdigital system, can interfere not only with separation of the fingers but also with flexion at the metacarpophalangeal joints.

In planning skin incisions and skin flaps at the outset of any operation, one should take into account every existing scar. Flaps must not be based on a scarred area. In adherent zones, undermining may lead to skin necrosis. Sinuous scars outline flaps whose base must not be divided when the surgeon designs new exposures.

CIRCULATION

Even though the patient has no specific vascular disease, a careful study of the circulation is essential both preoperatively and postoperatively.

Recognition of vascular disease is important for the appreciation of tolerance to a tourniquet, i.e., induced ischemia, and for assessing the likelihood of postoperative edema. Vascular disease also makes necessary a more conservative attitude toward the remaining arterial trunks, especially after severe injuries. The following points merit special consideration in an examination of the circulation:

Color. The examiner notes whether the skin is pale, red, or cyanosed.

Distal Arteriolar Flow. The distal arteriolar flow is measured by the time taken for color to return to the nail bed after pressure.

The Pulse. The pulse classically taken at the radial wrist groove is not the only accessible one. The ulnar pulse is usually palpable at the entry to Guyon's canal. The radial artery can also be felt as it exits from the anatomical snuffbox at the proximal part of the dorsal aspect of the first web space; it should remain accessible at this point through the thumb window when the wrist is immobilized in plaster. The collateral digital arteries can be felt at the base of the finger, just anterior to the dorsopalmar cutaneous line in the patient with a supple skin and a strong pulse.

Arterial Territories. A simple clinical test aids in deciding whether the radial or the ulnar artery is responsible for the major arterial supply to the hand. This is the Allen test, which is carried out as follows: The patient is asked to raise and clench his hand to squeeze the blood out of the cutaneous vascular bed. Using his two thumbs, the examiner compresses the radial artery in the radial groove and the ulnar artery in Guyon's canal. The patient then opens his hand, but without hyperextending the fingers. The palm appears exsanguinated. The examiner now releases one of his thumbs and notes the time taken for the palm to recover its normal color. The maneuver is then repeated to test for the other artery. Predominance of the radial artery is common.

Venous Return. The venous return is more difficult to measure. Localized cyanosis is obviously a sign of venous stasis, but edema is the most common feature of an abnormal venous return. Two points are worth stressing here:

1. Edema is most readily demonstrable on the dorsum of the hand. When severe, it is obvious; if less marked, it rounds off the bony contours of the metacarpals. Minimal edema causes the disappearance of the shallow transverse furrows that are normally present in dorsal skin.

2. Edema of the palmar tissues is more easily overlooked. It becomes obvious when it is abundant enough to fill the concavity of the palm between the thenar and hypothenar eminences. More often, there is but slight infiltration of the tissues, which is just palpable and is suggested by limitation of flexion of the fingers.

Complementary Examinations. When the hand has a poor circulation, two complementary examinations can be performed—thermography, which provides information about distal perfusion, and arteriography, which reveals the condition of the remaining arterial supply.

TROPHICITY AND SWEATING

Trophic changes are due to vasomotor and neurological factors. To assess trophicity, one should examine not only the skin but also the nails and dorsal hairs as well as the thickness of the soft tissues, especially in the pulp.

The amount of sweating and its distribution also deserve close attention to provide information concerning possible vasomotor disturbances (reflex sympathetic dystrophy). Localized differences in sweat secretion indicate the presence of a peripheral nerve lesion.

THE NAILS

Examination of the nails is useful, not so much to detect disease involving the ungual tissue proper but as a guide to atrophic changes and to study of the

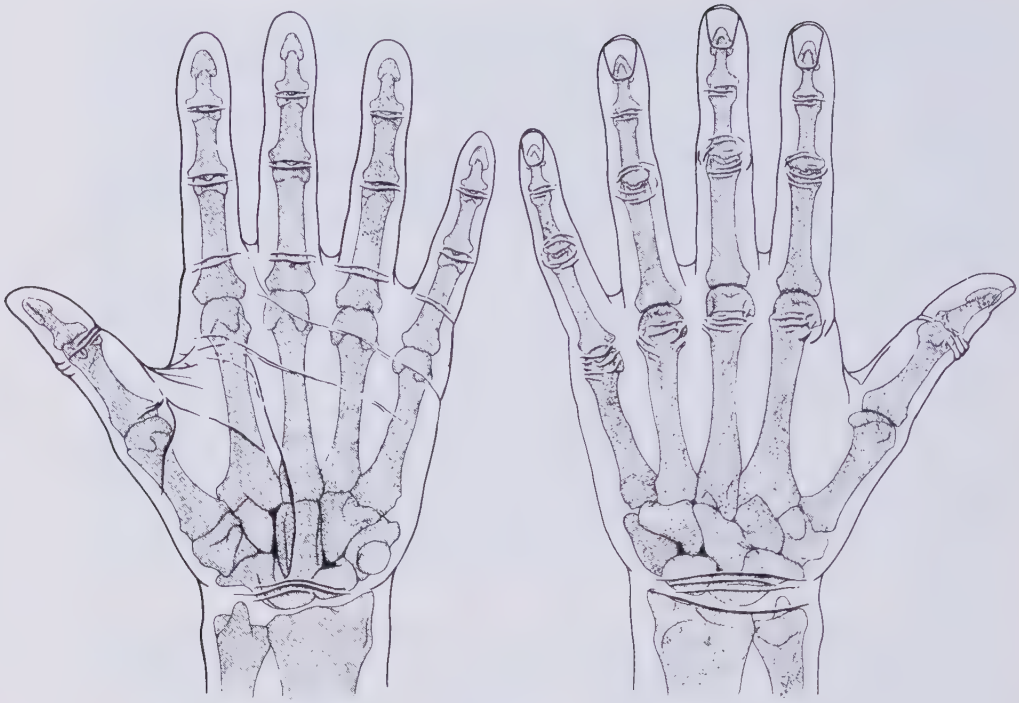


Figure 3–1. The cutaneous projection of the joint line.

pinch. The pulp tissue is supported by the nail matrix. Loss of, or damage to, the nail may affect the precision and power of the pinch.

EXAMINATION OF THE BONES AND JOINTS

BONE MORPHOLOGY AND LANDMARKS

The lower ends of the radius and ulna with their styloid processes are easily palpable on the dorsal, medial, and lateral aspects of the wrist. The interstyloid line is classically used to indicate the orientation of the distal aspect of the radius in the frontal plane.

The proximal row of carpal bones is also palpable in part. The lateral facet of the scaphoid can be felt at the bottom of the anatomical snuffbox; the tubercule on its anterior aspect is palpable in the extended wrist, just proximal to the thenar eminence. The posterior horn of the lunate can be felt dorsally, just proximal to the base of the third metacarpal with the wrist held in palmar flexion. The triquetrum is accessible on the medial border of the wrist when it is radially deviated. The volar aspect and ulnar border of the pisiform are palpable at the proximal part of the hypothenar eminence.

The second row of carpal bones cannot be identified by palpation. The floor of the carpal tunnel is also inaccessible, and the transverse carpal ligament conceals any derangement at that level (Fig. 3–1).

The metacarpus not only is easily palpable but is visually identifiable on the whole of the dorsum of the hand. The third metacarpal—the axis of the hand—is a landmark of wrist movements. The styloid process, which projects

from its base, is easily palpable and marks the line of the carpometacarpal joints. The relative lengths of the metacarpals can be seen along the line made by the metacarpal heads with the metacarpophalangeal joints flexed (normally III/II/IV/V). Proximal displacement of one of the metacarpal heads indicates a shortening of the corresponding metacarpal. Abnormal rotation after a metacarpal fracture can be diagnosed by observing flexion of the metacarpophalangeal joints. Malrotation is manifested by ulnar or radial deviation of the corresponding proximal phalanx; the greater the deviation, the more severe the malrotation.

The metacarpophalangeal joints are easily accessible on the dorsal and lateral aspects. They are not palpable in the palm, but their position can be derived from the flexion creases. The metacarpophalangeal joints lie approximately on a transverse line that begins in the distal palmar crease on the ulnar side and runs into the proximal crease on the radial border.

The phalanges and interphalangeal joints are visible and easily palpable on the dorsum and sides of the fingers, with the exception only of the proximal part of the proximal phalanx, which is embedded in the soft tissues of the web space. Deformities at that level, especially in the sagittal plane, are often difficult to detect clinically.

Distally lateral or anteroposterior deviations of the phalanges are clinically obvious. Defects of axial rotation in a digital segment are demonstrated, as with the metacarpals, by flexing the joint immediately distal: these defects are then confirmed by deviation of the next phalanx.

The axes of flexion are so arranged that flexion of all the metacarpophalangeal and proximal interphalangeal joints causes the fingers to converge toward the scaphoid. The examiner should note any variation from this.

CLINICAL MANIFESTATIONS OF ARTICULAR SWELLING AND EFFUSIONS

Wrist. Synovial effusion and thickening present clinically as a transverse swelling that appears first on the lateral and dorsal aspects of the joint. There may be simultaneous involvement of the extensor tendon sheaths. Dorsal swelling of the carpal joint may be difficult to differentiate from that originating in the inferior radiocarpal joint. Involvement of the inferior radioulnar joint presents as an exaggerated protuberance of the head of the ulna. Not infrequently there may be concomitant subluxation of the radioulnar joint, which, when reduced by simple pressure, produces a characteristic clicking sound.

Carpometacarpal Joints. Effusions in the small, closely packed carpometacarpal joints are seldom detectable clinically, with the possible exception of the trapeziometacarpal joint.

Metacarpophalangeal Joints. Swelling arising from the metacarpophalangeal joints is manifested mostly on the dorsal side. However, there is also some lateral swelling that fills the adjacent intermetacarpal depressions and tends to obscure the normal projection of the metacarpal heads on the dorsal side of the hand.

Interphalangeal Joints. Swelling and effusions at these joints characteristically result in a spindle shaped deformity at the level of the affected joint. The deformity is also perceptible on the dorsal side under the thin extensor apparatus.

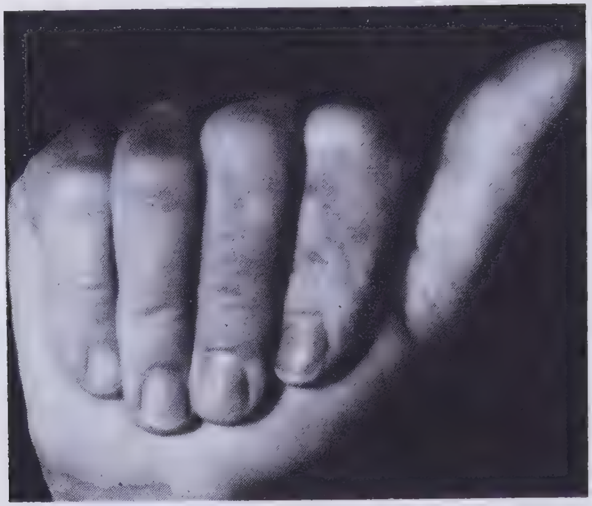


Figure 3–2. Convergence of the fingers toward the scaphoid tubercle in flexion.

PASSIVE MOBILITY OF THE JOINTS

Passive mobility of the joints does not depend exclusively on articular freedom. It may be limited by contractures of the skin and soft tissues as well as by obstruction to tendon movement. Loss of mobility in any joint should always be measured by comparison with its contralateral equivalent.

The Wrist

The bone landmarks used for the measurement of wrist mobility are the skeleton of the forearm and the third metacarpal. Measurements taken on the ulnar side of the hand should be avoided, because they include the specific mobility of the fifth carpometacarpal joint.

Two factors interfere with accurate measurements and may reduce their accuracy. The relative contributions of the radiocarpal and intercarpal joints cannot be measured separately; also a deviation of the distal facet of the radius in the sagittal plane modifies mobility of the joint but can be measured only radiologically.

Flexion or Palmar Flexion. The amplitude of palmar flexion is somewhat greater than that of extension, about one-third of the amplitude of movement occurring at the intercarpal joints (Fig. 3–2). Movement is measured with the limbs of the goniometer placed on the dorsal aspects of the forearm and third metacarpal, over the convexity of the flexed wrist. Mean flexion as measured by Wynn-Parry (in 100 young males) was 75 degrees, with a range of 52 to 93 degrees.

Extension or Dorsiflexion. The intercarpal joints provide about half the amplitude of extension. Goniometry is performed with the limbs of the instrument on the palmar aspects of the forearm and the third metacarpal across the palmar convexity of the extended wrist. Wynn-Parry's average extension reading (in 100 young males) was 64 degrees, with a range of 42 to 79 degrees.

Abduction and Adduction. Clinical examination of abduction or radial deviation and adduction or ulnar deviation movements in the wrist reveals the

contribution of the frontal deviation of the glenoid surface of the radius only if the interstyloid line is examined first. Adduction and abduction occur mostly at the radiocarpal joint and partly at the intercarpal joint; the contribution of each cannot be assessed clinically. Adduction-abduction is measured with the wrist held straight. The goniometer limbs are placed on the dorsal aspects of the forearm and third metacarpal. Mobility in this plane is reduced when the wrist is extended and is virtually absent if the wrist is flexed. Abduction is normally less—19 degrees on the average, with a range of 11 to 39 degrees. Adduction readings show a mean of 29 degrees, with a range of 19 to 35 degrees (Wynn-Parry).

The Carpometacarpal Joints

There is normally no clinically detectable mobility at the second and third carpometacarpal joints. Movement at the fourth carpometacarpal joint is limited to only a few degrees in the sagittal plane, and, although detectable, it is virtually impossible to measure accurately. The fifth carpometacarpal (metacarpohamate) joint has an appreciable mobility, which is important functionally in adaptation to the transverse arch of the palm and surgically in phalangization of the fifth metacarpal. Movement occurs in an almost sagittal plane, which is slightly oblique toward the axis of the hand. It can be observed clinically on the ulnar side of the hand when the head of the fifth metacarpal is mobilized, and it is measured by reference to the third metacarpal, which is fixed. The overall amplitude is about 20 degrees.

The first carpometacarpal (trapeziometacarpal) joint is functionally the most important, because it allows movement of the whole column of the thumb. Movements at this joint are so complex that they must be expressed conventionally. It is likely that in the movements considered, peritrapezial mobility does intervene. In practice, the movements are broken down as follows:

Outward Movement of the Thumb in the Plane of the Palm. At rest, the first metacarpal lies against the second; it moves away from the second metacarpal during abduction, which is the opposite of what happens in the movement of adduction (Fig. 3–3). The angle of abduction can be measured between the axes of the first and second metacarpals from the dorsal side and is usually between 40 and 50 degrees.

Movement of the Thumb Perpendicular to the Palm. At the start of this movement, the first metacarpal lies on the palmar surface of the second metacarpal; movement away from that surface is known as antepulsion, the thumb being placed in anteposition (Fig. 3–4). The measurement is taken between the ulnar border of the first metacarpal and the radial border of the second metacarpal; it varies between 40 and 80 degrees.

Axial Rotation (Pronation-Supination of the Thumb Column). This component, which intervenes in movements of the trapeziometacarpal joint during opposition, is difficult to assess clinically. One should watch for the changing orientation of the dorsum of the first metacarpal, and of the nail, during the movement from full abduction to full anteposition. This is the long range of the first metacarpal. Rotation of the first metacarpal is best demonstrated in this way, and rotation of the phalanges is not taken into account.

The following corollaries merit consideration:

1. In practice, whatever the origin of the movement, the plane of the second metacarpal represents the extreme limit of displacement of the first metacarpal toward the axis of the hand.

Figure 3–3. Abduction of the thumb. Maximal separation in the plane of the palm is evaluated clinically by measuring the angle made by the first and second metacarpals.

2. A quantitative assessment of the movement of retropulsion is of little practical value. It is the movement that carries the first metacarpal from full abduction to a point behind the plane of the hand. Its amplitude rarely exceeds 10 degrees.

Opposition. Opposition is a complex active movement, to be discussed on page 123.

The Metacarpophalangeal Joints

Flexion-Extension. Flexion-extension is measured by the angle formed with the limbs of the goniometer placed on the dorsal surfaces of the proximal phalanx and its corresponding metacarpal (Fig. 3–5).

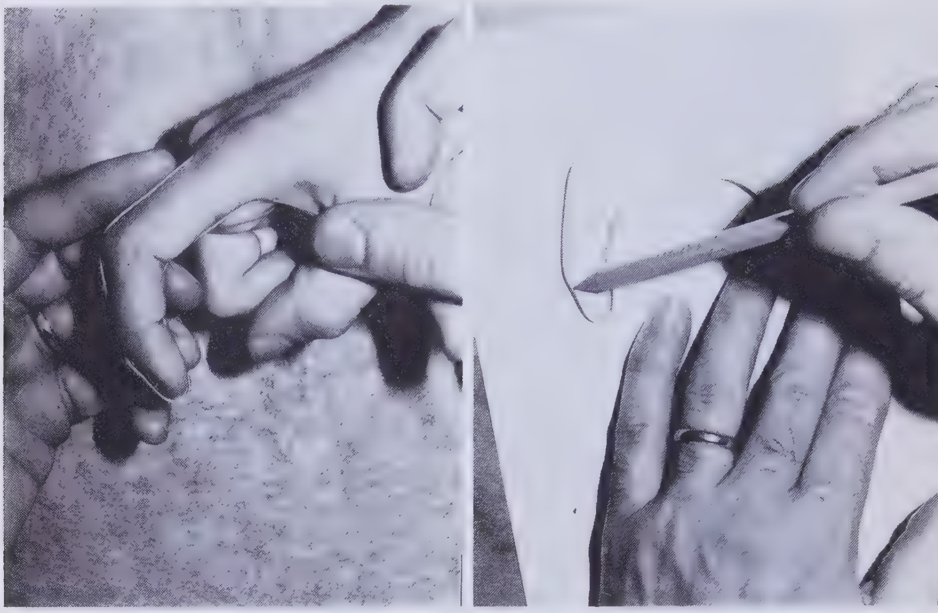
Glanville has described a simple procedure to determine successive angles of flexion and extension during re-education (Fig. 3–6). It consists of placing on the dorsal aspect of the digit a malleable metal filament that is adapted to the angles of the phalanges. The filament is then removed and used as a template to make a diagram of the state of the mobility. Successive drawings demonstrate progress.

Flexion. Flexion is invariably less in the index than in the other fingers. The average is 82 degrees, with a range of 61 to 96 degrees (Wynn-Parry). The amplitude is about the same for the middle, ring, and little fingers, i.e., a mean value of 88 degrees, with a range of individual variations—52 degrees (little finger) to 104 degrees (middle finger; Wynn-Parry).

Metacarpophalangeal Extension. There are great variations in metacarpophalangeal extension from one subject to another. Active extension varies between 10 and 20 degrees, but passive extension can reach 90 degrees in loose jointed subjects. Conversely, it may be nil in subjects whose soft tissues are

Figure 3–4. Anteposition of the thumb. Separation of the thumb perpendicular to the plane of the palm can be measured by the angle formed by the first and second metacarpals. Simultaneous axial rotation can be observed, which modifies the orientation of the plane of the nail.

Figure 3–5. Examination of joint amplitude can be carried out by using a goniometer placed on the dorsal aspect of a finger.



A B

Figure 3–6. As shown by Glanville, the mobility of the joints of the fingers can be recorded by molding a malleable metal strip on the finger (*A*), whose contour is recorded on paper (*B*).

unusually stiff. This point deserves careful study in patients with paralysis of the intrinsic muscles of the fingers (Fig. 3–7).

Sideward movements are normally possible at the metacarpophalangeal joints. They must be tested with the fingers held straight, because they become impossible (as a result of increased tension of the collateral ligaments) once the fingers are flexed. In the normal hand freedom of movement is always greater on the ulnar than on the radial side.

Figure 3–7. In a normal subject active hyperextension of the metacarpophalangeal joint remains possible when the wrist is dorsiflexed in spite of active interphalangeal flexion.

Ulnar movement is greatest in the index finger (mean, 42.7 degrees) and smallest in the ring finger (mean, 24 degrees). Radial movement is greatest in the little finger (average, 29.4 degrees) and least in the middle finger (Hakstian and Tubiana, 1967).

Some passive axial rotation is usually possible when the metacarpophalangeal joint is extended.

None of the points just mentioned apply to the metacarpophalangeal joint of the thumb. The range of flexion is usually less than that in the other digits. Wynn-Parry mentions 55 degrees on the average, with extremes of 36 and 89 degrees. Extension is virtually nil, except in loose jointed individuals. Side to side movement is more limited than in the fingers, and the relative ranges are reversed; i.e., ulnar movement is nil, while radial movement is present but limited. The former movement is tested by pressing on the radial border of the first phalanx and forcing the thumb into retropulsion. Radial movement can be produced passively when the thumb is forced into maximal antepulsion by pressure on the ulnar border of the first phalanx. Axial rotation is functionally important but, as mentioned already, is difficult to dissociate clinically from the axial movements of the first metacarpal. It can be produced, however, if a torsional force is applied to the head of the first phalanx. If this maneuver is carried out with the thumb in full abduction, it is possible passively to exaggerate supination of the pulp. If the maneuver is carried out with maximal antepulsion, pulp pronation can be passively exaggerated.

The Proximal Interphalangeal Joints

The proximal interphalangeal joints have but one plane of movement, namely, flexion-extension; they are remarkably stable laterally. Mobility is measured by the angle formed by the limbs of the goniometer on the dorsal surfaces of the proximal and middle phalanges.

The range of flexion is usually more than 100 degrees (Wynn-Parry's averages for passive flexion range from 104 degrees for the little finger to 114 degrees for the ring finger). Some individuals have more limited flexion, the lowest figures having been recorded by Wynn-Parry in the index finger. Extension is usually nil at the proximal interphalangeal joints. It is also worth noting that it is the orientation of the axes of flexion at these joints that produces the normal convergence of the fingers toward the scaphoid.

The Distal Interphalangeal Joints

The distal interphalangeal joints move essentially in flexion and extension, but slight side to side movement is also usually possible. The range of flexion is normally less than that in the proximal joints (average, 80 degrees; Wynn-Parry). Some degree of passive extension is normal (about 30 degrees); it is more marked in the index finger.

EXAMINATION OF THE MUSCLES AND TENDONS

CLINICAL MANIFESTATIONS OF TENOSYNOVITIS

The patient with tenosynovitis complains of "clicking" or "sticking," and objectively crepitus may be felt over the involved tendon. More often, however, tenosynovitis presents as a localized swelling.

Extensor Tendons of the Fingers. Synovitis of the extensor tendons presents as an elongated swelling on the dorsum of the hand and lower forearm. At the wrist the swelling is usually partly concealed by the extensor retinaculum. In severe cases the swelling may take the shape of an hourglass.

Extensor Tendons of the Thumb. The extensor tendons of the thumb are the abductor longus, extensor brevis, and extensor longus. Involvement of these tendons is signaled by swelling over the lateral aspect of the lower end of the radius. Proximally the swelling disappears where the tendons run through the osseofibrous retinacular channels on the posterior aspect of the lower end of the radius. Crepitation can often be felt at that level.

Flexor Tendons. In the wrist and the forearm, inflammation of the synovial sheaths produces diffuse swelling of the soft tissues above the proximal carpal crease. This disappears more distally owing to the presence of the transverse carpal ligament. The swelling can be minimal even in severe synovitis and should be carefully looked for and compared with the other side. In the palm, swellings and synovial effusions are difficult to detect clinically except in the index finger, where they present at the base of the finger. In the digital canal, synovial disease must be suspected when flexion is painful or limited and when no joint disorder can be found.

Synovial swelling is judged by palpating the soft tissues that line the palmar surface of the phalanges. Using two fingers of one hand, the examiner squeezes the soft tissues of the phalanx toward its palmar surface; with the other hand, he searches for a thickening of the bulging tissues by comparing with the healthy fingers.

TENDON MOBILITY: LIMITATION OF MOVEMENT DUE TO MUSCLE CONTRACTURES AND PERITENDINOUS ADHESIONS

All the maneuvers described here are based on relaxation of the shortened or adherent muscle by making use of the mobility of the joint immediately distal to the site of the disorder. These maneuvers serve to differentiate between articular and musculotendinous limitations in cases of reduced mobility of the fingers. They also help to confirm clinically contracture of certain muscles. Their practical applications are as follows:

Limitation of Extension of the Fingers by Contracture of the Fleshy Part of the Flexors. This is the case in Volkmann's contracture. Flexion of the wrist partly or totally corrects the digital claw deformity. The freedom of movement at the joint can then be tested, but one should also assess the degree of muscle shortening in terms of the amount of carpal flexion required to straighten out the fingers.

Limitation of Extension of the Fingers by Flexor Tendon Block. Flexion of the joint immediately distal to the block allows extension of the more distal phalanges. In practice this test is often of only limited use in the fingers, because flexor tendon adhesions are usually diffuse.

Bunnell's Test. Bunnell's test involves a similar maneuver, which aims at detecting contractures of the interosseous muscles. In such cases flexion of the interphalangeal joints is impossible as long as the proximal phalanx, i.e., the metacarpophalangeal joint, is held in extension. Conversely, flexion of the metacarpophalangeal joint relaxes the interosseous muscles, and interphalangeal joint flexion becomes possible. We shall see later that in the opposite

maneuver, limited muscular contraction can be detected if the fleshy part of the muscle is put under tension.

GLOBAL MOVEMENTS IN THE HAND

In the course of a routine clinical examination it is impossible to test the whole motor system of the hand. In this section, therefore, we shall consider movements that contribute to everyday manual activities and study overall function rather than individual muscle action. Such function is the result of a number of factors affecting the joints (stiffness), the muscles (power), the tendons (adhesions or deviation), and the skin (scars). A test of function therefore is not used to diagnose or localize a specific lesion, as this has been dealt with already. We shall study the movements involved in opening and closing the hand, in opposition, and in the common grips.

OPENING THE HAND

The movements involved in opening the hand determine the maximal size of the object that can be grasped. Such movements thus can be studied by asking the patient to grasp cylindrical objects of increasing sizes.

In the fingers the quality of the movements depends on the efficiency of the extensor muscles (radial palsy) and the mobility of the joints (hyperextension of one joint may sometimes compensate for fixed flexion in another). One flexed finger is sufficient to prevent the hand from grasping a sizable object.

In the thumb the movements depend on the ability of the first web space to open up. This is achieved by the action of the extensors and abductors of the thumb, but passive opening of the web depends mostly on the mobility of the carpometacarpal and metacarpophalangeal joints. Hyperextension of the latter may compensate to a certain extent for stiffness of the former.

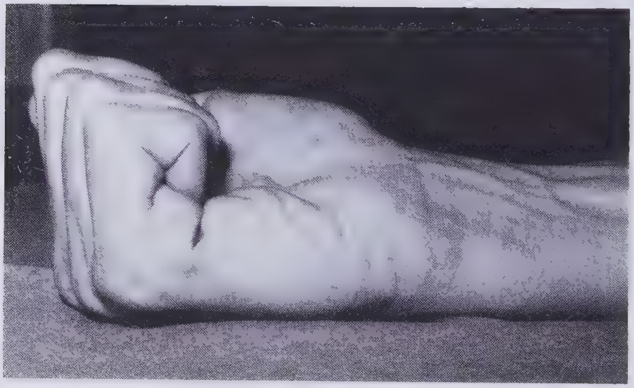
CLOSING THE FINGERS

As we have seen earlier, closing of the fingers involves a sequence wherein the metacarpophalangeal joint, proximal interphalangeal joint, and distal interphalangeal joint are flexed in turn. If this normal sequence is disturbed and the interphalangeal joints are the first to flex, grasping of an object will become impossible.

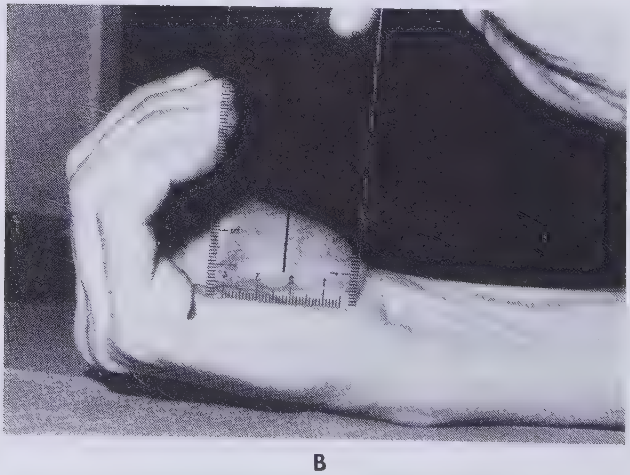
The amplitude of the flexion, however, determines the size of the smallest object that the closed fingers can hold safely. It also determines the strength with which objects of a slightly larger size can be held. This amplitude depends on the range of mobility of the flexors, the suppleness of the joints, the overall flexor power, and the pliability of the soft tissues. It is usually best appreciated in terms of the distal palmar crease.

Normal morphological variations and the usual presence of two distinct creases define this landmark as a transverse line joining the ulnar end of the distal palmar crease to the radial end of the proximal palmar crease (Fig. 3–8). In the normal hand the terminal part of the four digital pulps can be actively brought into contact with the palm along this line (Fig. 3–9). When the fingers come into contact with the palm on the proximal side of this landmark, this

Figure 3–8. The palmar crease for reference is a line joining the ulnar extremity of the palmar crease distal to the radial extremity of the proximal palmar crease.



A



B

Figure 3–9. *A*, Complete flexion brings the distal extremities of the pulps to the palmar crease. *B*, The palm-pulp distance measures in centimeters the total lack of flexion.

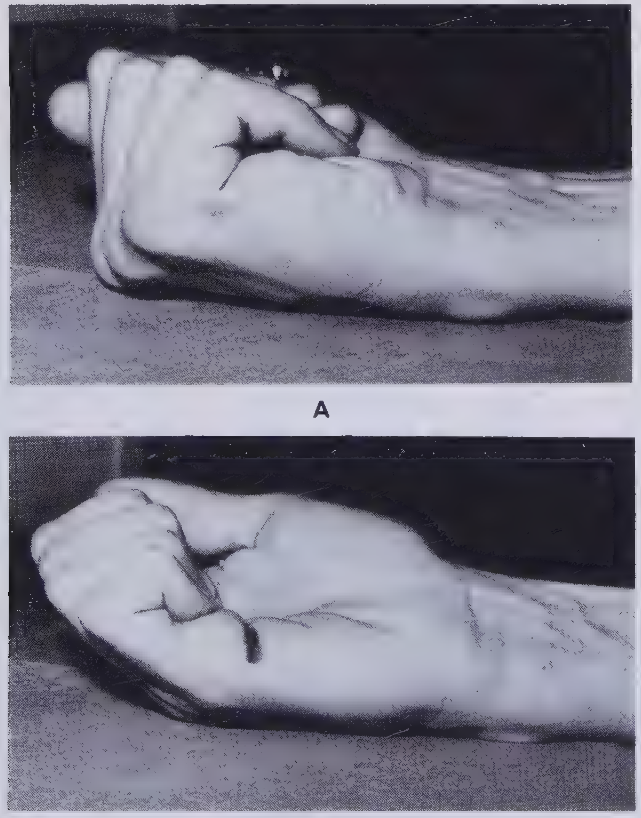
usually implies a flexion deficit in the interphalangeal joints, which is more or less compensated for by increased metacarpophalangeal flexion (Fig. 3–10). If the flexion deficit is more severe, the pulps will fail to reach the palm. The overall flexion deficit is then measured in terms of the distance in centimeters between the pulps and the palm.

OPPOSITION

From the point of view of the mechanics and of the motor muscles involved, the movement of opposition is particularly complex. We shall consider it under three headings.

1. The ability of the thumb successively to oppose the four fingers during the "long range" of the first metacarpal, that is, staying wide of the palm and keeping the first web space open. As long as this ability is retained, opposition will be virtually normal.

2. The ability of the thumb successively to oppose the four fingers during the short range of the first metacarpal, that is, with the first commissure closed. Preservation of only this type of opposition constitutes a major functional handicap.



A

B

Figure 3–10. *A*, Isolated interphalangeal stiffness can be compensated for by hyperflexion at the metacarpophalangeal joint. However, the pulps then touch "proximal" to the palmar crease. *B*, Isolated metacarpophalangeal stiffness can be compensated for by interphalangeal hyperflexion, but the pulps then touch the palm distal to the palmar crease.

3. Rotation of the pulp of the thumb, which determines the efficiency of a pulp grip. Between the position of full extension and abduction of the thumb in the plane of the palm and that of opposition with the little finger, pulp rotation may reach 90 to 120 degrees. It is normally possible to place the pulps of the thumb and little finger in the same plane at the end of the movement of opposition.

NATURE AND POWER OF THE COMMON GRIPS

"Spherical" Grip. The "spherical" grip is used to catch hold of rounded objects. The four fingers and the thumb are extended and play an equal part in the grip. Grip is tested by asking the patient to lift a rounded object (e.g., an ashtray).

"Cylindrical" Grip or Grasp. Grasp is the commonest form of power grip; it is used for handling tools and machinery controls. It is produced by wrapping the flexed thumb and fingers around the object. The size of the object that can be grasped depends, as we have seen, on the ability of the fingers to close. This grip is tested by using objects of decreasing size.

Prehensile force usually means the power grip. It is measured with a metal blade dynamometer of standard caliber (Fig. 3–11). The readings are interpreted by comparison with the contralateral limb because there are wide individual differences.

According to a study by Swanson, the dominant hand is only 5 to 10 per cent more powerful than its counterpart. However, these figures are probably valid only in a population whose left handed members are not taught to alter their dominance.

Age and sex also have an influence on the force of prehension, the average for women being one-third to one-half that for men. In men prehensile force decreases after the age of 50 (in women after 40) by about 10 to 20 per cent.

Thumb-Finger Pinch. Measurement of thumb-finger pinch requires a special dynamometer because the forces generated are smaller.

The thumb-unidigital pulp-to-pulp pinch is not frequently used. Its clinical study is the basis for Froment's sign. The patient holds a sheet of paper between the pulp of the thumb and that of the index finger, and the examiner tries to

Figure 3–11. Measuring the strength of digital-palmar grip by a metal spring dynamometer.

pull it away. If the adductor pollicis is paralyzed, the patient, in an effort to hold onto the sheet, will flex the distal phalanx of the thumb (positive Froment's sign). It is worth noting, however, that the strongest thumb-unidigital pinch is that involving the middle finger.

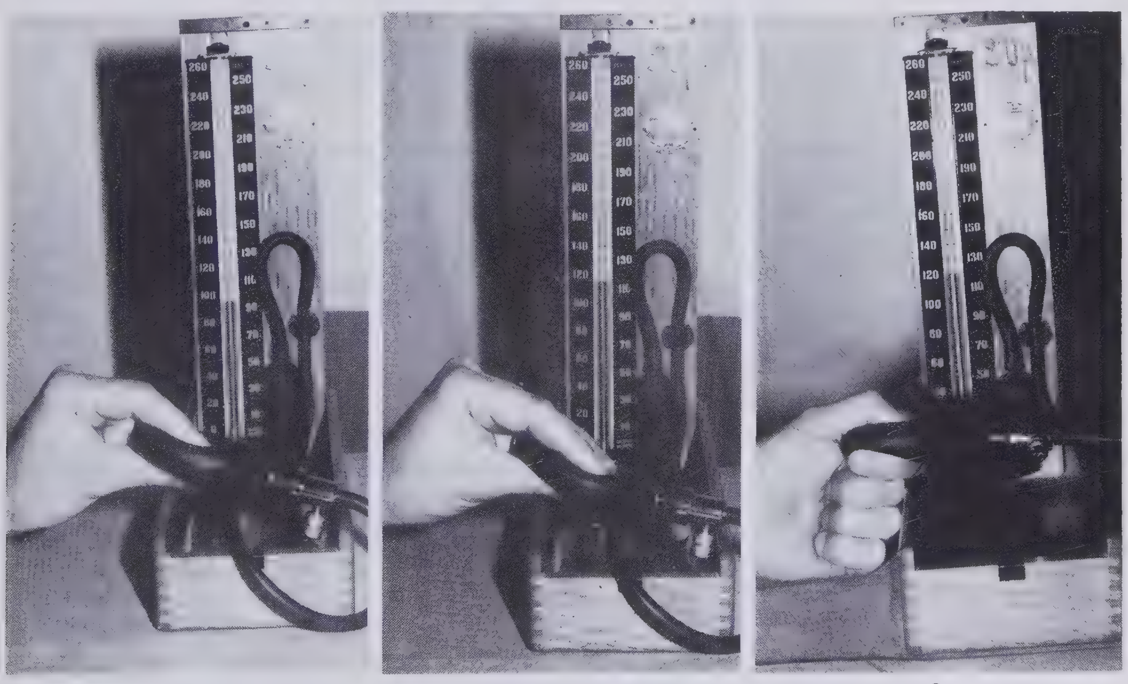
The only common thumb-unidigital pinch is the terminoterminal hold between the thumb and index finger, which is used for picking up very small objects. The important factor here is not so much the force as the sensitivity of the pulps, which is responsible for its precision.

The most common thumb-digital pinch is that between the pulps of the thumb, index, and middle fingers (Fig. 3–12). This hold is most powerful when the interphalangeal joint of the thumb is extended. It is studied by asking the patient to unscrew a bottle top or to hold a small cylindrical object (pen or pencil), which the examiner tries to pull away. The power of this grip, measured with an adapted dynamometer, varies between one-fifth and one-sixth of the so-called force of prehension.

In the subterminal lateral pinch (or key pinch), the proximal part of the pulp of the thumb is opposed to the lateral aspect of the middle phalanx of the index finger. It must be examined because of its practical importance (Fig. 3–13). It is usually slightly weaker than the tridigital pinch already described. In major multiple palsies, it is often the only type of pinch that can be restored by palliative surgery.

SKIN SENSATION

Investigation of nerve lesions in the upper limb should always include the testing of cutaneous sensation. As we shall see, sensory loss or sensory changes



A B C

Figure 3–12. Measuring pollicidigital pinch using a mercury manometer. *A*, Terminoterminal thumb-index pinch. *B*, Terminoterminal tridigital pinch. *C*, Terminolateral pinch (key pinch).

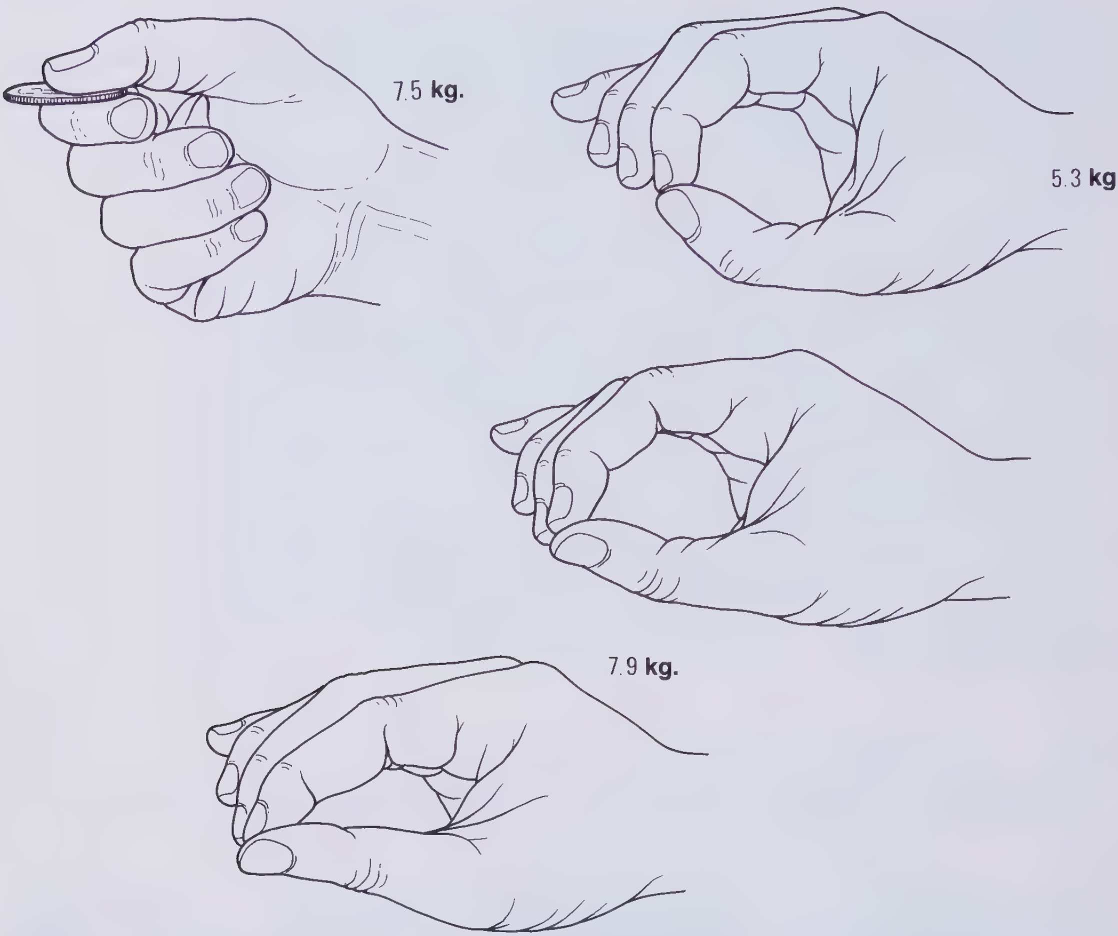


Figure 3–13. Average force of pollicidigital pinch. (After Wynn-Parry.)

in the hand result in disuse of the denervated segment even if the motor supply is intact. However, the methods of testing sensation must be modified and interpreted in the light of the special nature of superficial sensation in the hand. Classic tests are too gross to yield accurate information about the functional value of hand sensibility. Being a sensory organ in its own right, the hand deserves specialized testing to evaluate its tactile properties.

TINEL'S SIGN

The test for Tinel's sign is frequently applied following surgical repair of nerves. The test is used to assess the progress of nerve regeneration distal to the lesion and is used when no sign of peripheral reinnervation has yet appeared. Tinel's sign is discussed further in Chapter 6 (p. 208).

CLASSIC NEUROLOGICAL TESTS

The neurological tests used to determine the skin sensibility of the hand are those generally used in the study of sensibility. They aid in localizing the

nerve trunk affected and in following the progress of reinnervation. One should use them on the healthy hand first to allow the patient to understand what is being looked for. When one is using repetitive stimuli, they should be applied at varying intervals to discourage false answers.

The tests are described in Chapter 5.

MOBERG'S NINHYDRIN TEST

The Ninhydrin test deserves special mention because of its objectivity: it is the only test that does not require the cooperation of the patient and that is unaffected by variations in technique. The test is based on the direct relationship between the sensory supply to the skin and the sympathetic supply to the sweat glands in the same area of skin. It relies on the characteristic color reaction of Ninhydrin with the amino acids present in sweat.

Practical Aspects. The test can be applied to any denervated area of skin, but in practice only the pulps are Ninhydrin tested. Sweating can be induced by exercising the patient or giving him a hot drink, but in the normal subject, unpremedicated and at normal room temperature, sweat secretion is usually quite adequate for testing purposes.

If secretion in the normally innervated areas is overabundant, however, and threatens to flood the suspected areas, the hand should first be washed and dried.

The paper used should be dry, nonporous, and free from substances capable of initiating a color reaction with Ninhydrin. It should, of course, also be free from contamination by the examiner's sweat. The pulps are applied to the paper and rolled across from side to side. The fingerprints are outlined in pencil and developed in Ninhydrin.

Ninhydrin can be preserved for several months as a 1 per cent solution in acetone; it is acidified immediately prior to the test (a few drops of glacial acetic acid in 10 ml. of the solution) but will keep for only one or two weeks in the acid form.

The paper is immersed in the Ninhydrin solution, rapidly dried, and then heated (to 100 to 120° C. for five to 10 minutes in an oven). The fingerprints will then become visible but must be fixed, preferably a few days later. The fixing agent is a 1 per cent copper nitrate solution in a mixture of 5 per cent water and 95 per cent methyl alcohol or acetone, acidified with a few drops of concentrated nitric acid.

Interpretation. The result is read in terms of the colored dots, which represent the orifices of the sweat glands and are distributed according to the dermatoglyphic pattern. The number of dots and the color intensity are compared in the normal and denervated areas. Insensitive areas fail to secrete, and their impressions on the sheet of paper remain colorless.

Limitations, Use, and Significance. Sweat secretion may persist when sensation is absent, such as in flaps and when the peripheral lesion lies proximal to the sympathetic afferent junction. This is the case in traumatic lesions of the brachial plexus at the nerve root. The Ninhydrin test is then the best way of localizing the lesion.

The text is conclusive only when colored prints are absent in the denervated area. It can then be used to map out the anesthetic area with accuracy and to confirm its presence without requiring the cooperation of the patient. It is therefore useful in children and when a lasting record is desired. It is also the

only way of demonstrating objectively the paradoxical preservation of sensation after a nerve injury, probably because of anomalies of the sensory nerve supply.

Anesthetic blocking of a healthy nerve trunk suppresses sweat secretion in its territory; an anomalous nerve supply can be demonstrated by comparing the fingerprints before and after the block.

When sweat marks are present, or reappear, in the anesthetic or hypoesthetic area, the test loses most of its value. Admittedly the presence of a reduced number of sweat marks is compatible with marked hypoesthesia, but the presence of normal or subnormal sweat marks does not constitute evidence of sensory recovery. The Ninhydrin test therefore is of no value in a qualitative assessment of sensation. Sensory recovery is not synonymous with a positive Ninhydrin test.

TEST OF TACTILITY (TACTILE GNOSIS)

In our practice two tests have proved useful in accurately assessing cutaneous sensation in the hand. Both are reliable tests of the tactile sense (tactile gnosis). They are Weber's two point discrimination test and Moberg's pick-up test, which is comparable to Seddon's coin test. They are described in Chapter 5.

DEEP SENSIBILITY

Study of deep sensibility is not in current use in surgical disorders of the hand, because problems of deep sensation of the hand are less important than those of superficial sensation in lesions of nerve trunks.

Occasionally one must evaluate deep sensibility with precision when palliative surgery is contemplated in cases of central paralysis and in pure lesions of the motor cortex, as, for instance, infantile hemiplegia. In such cases one must evaluate the state of basic deep sensation while looking at the same time for disruption of the position sense of the fingers.

In order to test joint position sense, the examiner holds each side of the digit and flexes or extends the interphalangeal joints. The patient, who has his eyes closed, reports the position of the joints and can be asked to mimic this position by moving the normal contralateral digits. Sensibility to pressure is tested by asking the patient to weigh in his hand objects of different weights. Sensation to vibration is determined by using a tuning fork placed on the metacarpal heads and on the radial and ulnar styloid processes.

The study of recognition of the shapes of objects, or stereognosis, is an important part of this examination, because this ability is necessary for the hand to keep its functional value, no matter what partial substitution may be provided by vision when deep sensation is lacking. One can evaluate only the extent to which this sensibility is preserved.

Stereognosis can be lost by two mechanisms. Sometimes objects are not recognized because their shape, size, texture, and weight are poorly identified. In other cases these different characteristics are correctly analyzed but the patient is unable to correlate them or to recognize in them the significant characteristics for identification of the object. These purely tactile asymbolisms are rare.

Whatever the cause of the astereognosis, the problem may be sufficiently great to be a contraindication to palliative surgery.

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CHAPTER FOUR

CLINICAL EXAMINATION AND FUNCTIONAL ASSESSMENT OF THE UPPER LIMB

ANALYTICAL EXAMINATION OF THE MUSCLES

We shall deal here with tests that are used to demonstrate clinically the motor activity of each of the muscles of the upper limb. These tests do not necessarily make use of the normal activity of each individual muscle but aim at dissociating the muscle from its synergists. Most of the maneuvers described are used to produce active mobilization of a more distal segment; it is not so much the actual contraction of a muscle as its efficiency that is tested.

Weakening or disappearance of voluntary movement may be due to one of several causes: Paralysis of the afferent nerve, destruction of muscle tissue (often as a result of ischemia of the fleshy part of the muscle), rupture of the tendon, and tendon block because of adhesions are the more obvious causes. However, one should remember that alteration at its point of angulation will reduce or annul the efficiency of a muscle. This is the case when the pulleys of the flexors are damaged or when the extensor tendons are dislocated into the intermetacarpal spaces. It is also obvious that these tests are valid only if the joint has a normal range of movement.

An abnormal hand posture may be characteristic and establish the diagnosis, as with a typical ulnar claw, or as with wrist drop and flexion of the wrist and metacarpophalangeal joints, pathognomonic of radial nerve palsy (Figs. 4–1, 4–2).

Somewhat less typical is the dissociated radial palsy simulating an ulnar claw in which extension of the thumb and index and middle fingers is preserved (Marie et al., 1917).

Dissociated median nerve forearm palsy resulting from compression or sectioning of the anterior interosseous nerve supplying the flexor pollicis longus, the radial half of the flexor digitorum profundus, and the pronator quadratus also produces a characteristic deformity known as the "anterior interosseous nerve syndrome" (Kiloh and Nevin, 1952; Tinel, 1918; Fig. 4–3). During pinch the distal phalanges of the thumb and index finger cannot flex and stay in extension.

Clawing of the two ulnar digits, caused by paralysis of the interosseous muscle, is variable. It is usually absent in proximal lesions of the ulnar nerve, because the deep flexors of the ulnar fingers are also paralyzed. The deformity does not usually involve the index and middle fingers, for paralysis of the

Figure 4–1. Ulnar claw hand.

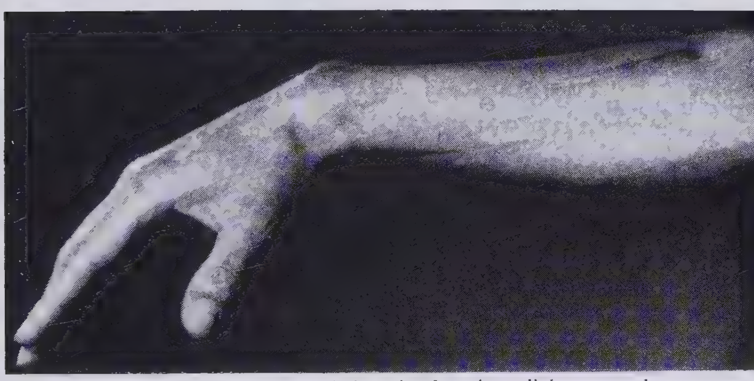


Figure 4–2. The characteristic wrist drop in radial nerve palsy.

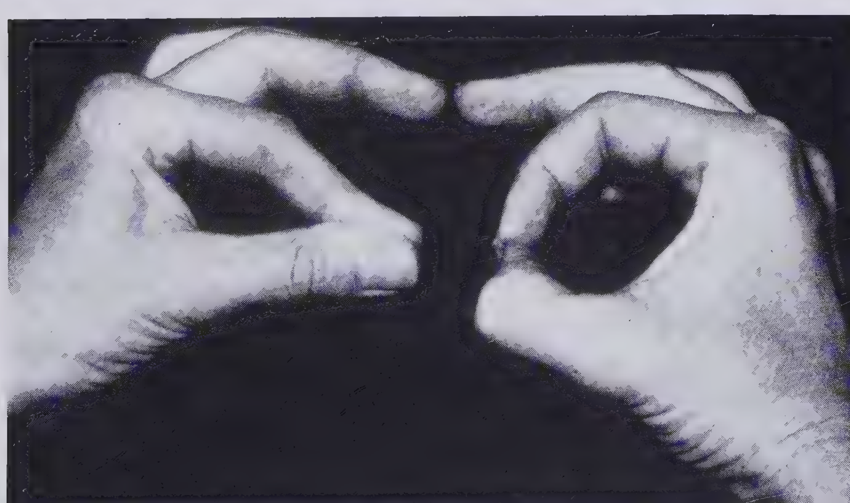


Figure 4–3. Typical pinch attitude in any anterior interosseous nerve palsy.

interosseous muscles is compensated for by the lumbrical muscles, which are supplied by the median nerve. There is a wide variation in the motor and sensory territories of the median and ulnar nerves.

EXAMINATION OF MOTOR FUNCTION

The main features of a motor palsy are muscle atrophy and the absence of voluntary contraction.

Demonstration of voluntary contraction is not always easy. Not all muscles are palpable. The nerve supply can be anomalous, and a contraction of a normally innervated muscle can be transmitted to the fibers of an adjacent paralyzed muscle. The reflexes must be tested and compared with those on the healthy contralateral side.

The key of this part of the examination is the study of voluntary movements. Accurate assessment of the individual muscles is essential. Muscle power is graded by using the Highet scale adopted by the British Medical Research Council (1941) or one of its variations. We use the version devised by Merle d'Aubigne (1956):

M0—no contraction.
M1—flicker (no joint motion).
M2—contraction with mobility with gravity eliminated.
M3—contraction against gravity.
M4—contraction with active movement of normal amplitude against gravity and some resistance.
M5—normal power.

Examinations are repeated periodically and the results are noted on an appropriate form, such as that shown in Figure 4–4.

We will stress here the importance of testing for movements originating in the arm, forearm, and shoulder. These examinations are mandatory in high trunk lesions and injuries of the brachial plexus (Fig. 4–5).

TESTING THE VOLUNTARY MOVEMENTS OF THE SCAPULAR MUSCLES

Serratus Anterior

Nerve supply: Long thoracic nerve ("respiratory" nerve of Bell; C5, C6, C7).

Action: Pulls the scapula forward against the ribs.

Test of muscle function: Using the upper limbs, the patient pushes his body away from a fixed plane. The medial border of the scapula is held against the thoracic plane by the serratus anterior unless the latter is paralyzed (Fig. 4–6).

Rhomboid

Nerve supply: Nerve to the rhomboid (C4, C5).

Action: Pulls the lower half of the scapula medially.

Test of muscle function: The patient attempts to push his shoulder backward

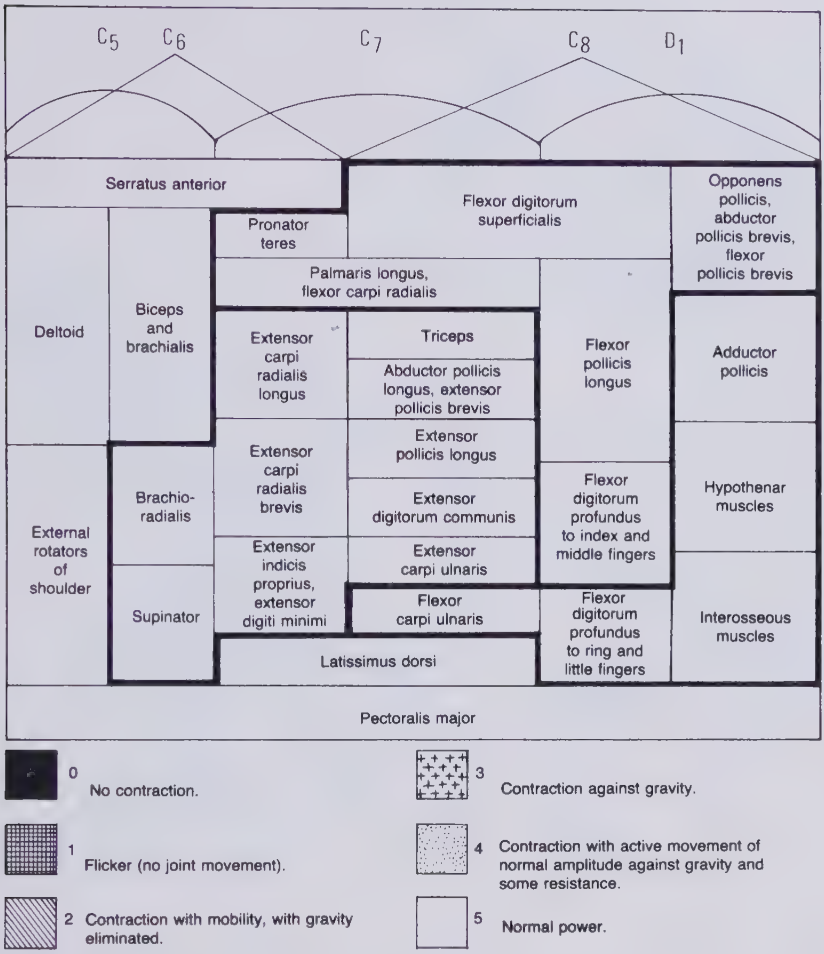


Figure 4–4. A standard form used to record motor function in the upper limb (after Merle d'Aubigne). The areas outlined in heavy black lines enclose those muscles usually supplied by the median, radial, and ulnar nerves. The area on the form for each muscle should be cross hatched or stippled according to its power (scale 0–5): M0, no contraction. M1, flicker of activity (no joint motion). M2, contraction + joint motion (gravity eliminated). M3, contraction + joint motion (against gravity). M4, contraction against gravity + some resistance. M5, normal power.

against resistance. Contraction of the muscle can be felt and sometimes seen (Fig. 4–7).

Analysis of Arm and Shoulder Movements

Abduction. Abduction of the arm at the shoulder joint is brought about by the middle part of the deltoid and the supraspinatus (Fig. 4–8).

Flexion. Flexion is produced by the anterior part of the deltoid, the clavicular head of the pectoralis major, the coracobrachialis, and the short head of the biceps (Fig. 4–9).

Extension. Extension results from the action of the posterior part of the deltoid, the latissimus dorsi, the teres major, and the long head of the triceps (Fig. 4–10).

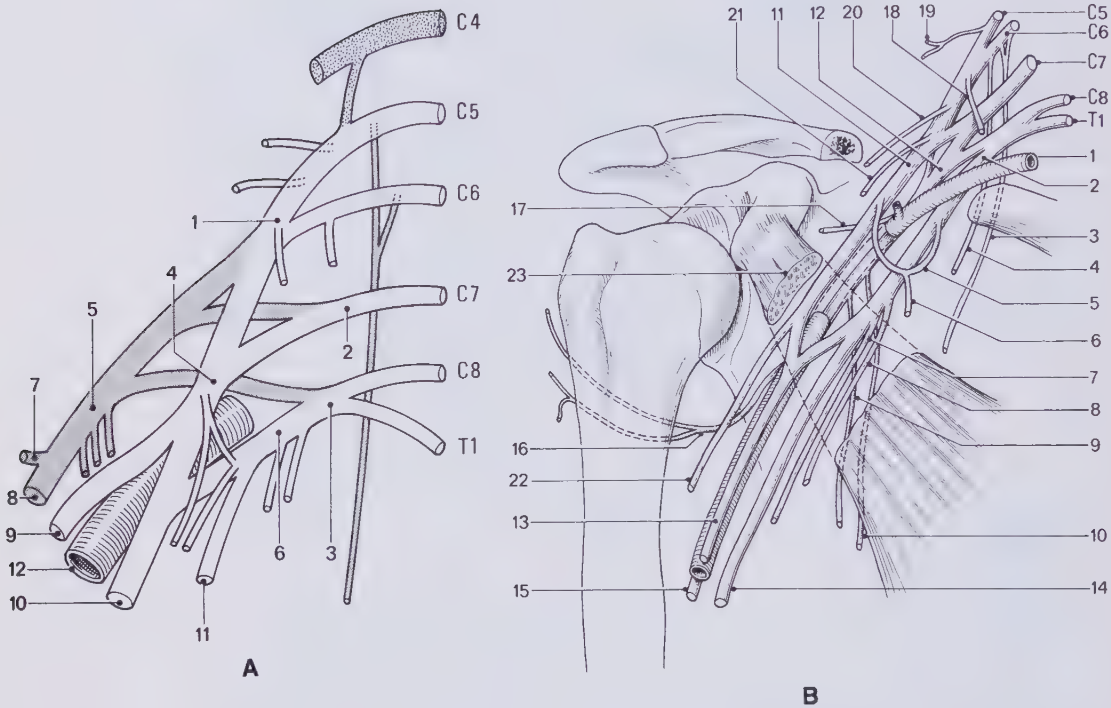


Figure 4–5. The brachial plexus. *A*, Structure. It is traditional to represent the structure of the brachial plexus schematically in the following manner: The fifth anterior cervical root (C5), after receiving the branch from the fourth root (C4), unites with the sixth root (C6) to form the superior trunk. The first thoracic root, after receiving a branch from the second thoracic root, unites with the eighth cervical root (C8) to form the inferior trunk. The seventh cervical root (C7) continues as the middle trunk. Each of these trunks divides into two divisions, one anterior and one posterior. The three posterior divisions unite to form the posterior cord from which the circumflex nerve and radial nerve arise. The anterior division of the superior trunk receives the anterior division of the middle trunk. They unite to form the lateral cord from which the musculocutaneous nerve and the lateral root of the median nerve arise. Finally, the anterior division of the inferior trunk remains independent and forms the medial cord from which the medial root of the median nerve, the ulnar nerve, and the medial brachial cutaneous nerve of the arm and forearm arise. 1, Superior trunk. 2, Middle trunk. 3, Inferior trunk. 4, Lateral cord. 5, Posterior cord. 6, Medial cord. 7, Axillary nerve. 8, Radial nerve. 9, Musculocutaneous nerve. 10, Median nerve. 11, Ulnar nerve. 12, Axillary artery. *B*, Branches of the brachial plexus. 1, Axillary artery. 2, Medial cord. 3, Nerve to serratus anterior. 4, Upper subscapular nerve. 5, Medial anterior thoracic nerve. 6, Anterior thoracic nerve. 7, Medial brachial cutaneous nerve. 8, Medial antebrachial cutaneous nerve. 9, Nerve to latissimus dorsi. 10, Nerve to teres major. 11, Lateral cord. 12, Posterior cord. 13, Median nerve. 14, Ulnar nerve. 15, Radial nerve. 16, Axillary nerve. 17, Inferior subscapular nerve. 18, Dorsal scapular nerve. 19, Nerve to subclavius. 20, Suprascapular nerve. 21, Lateral anterior thoracic nerve. 22, Radial nerve. 23, Pectoralis minor muscle.

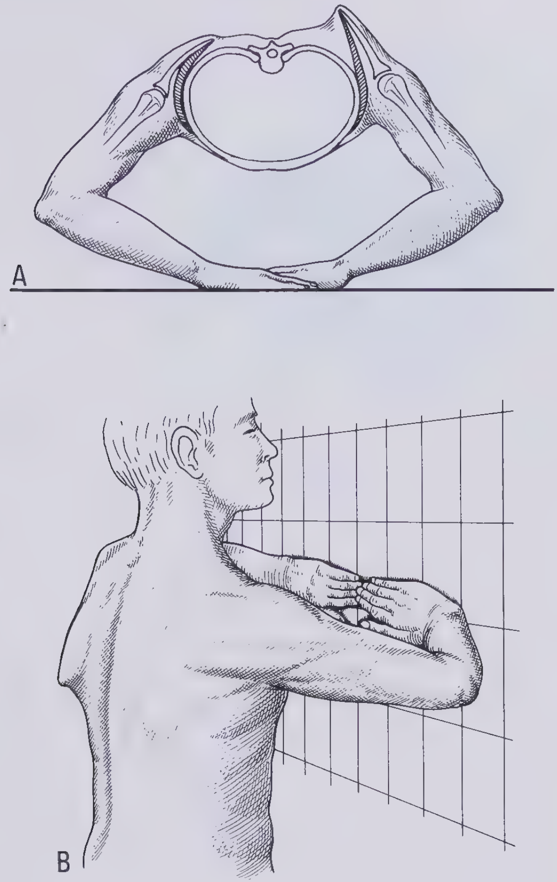


Figure 4–6. Serratus anterior palsy. *A*, Winging of scapula on the left side as seen in this cross section of the trunk. *B*, Clinical test to demonstrate winging of the left scapula.

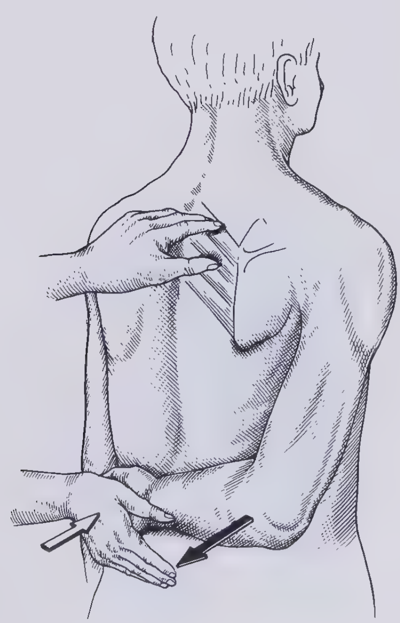


Figure 4–7. Paralysis of the rhomboids. With his arm behind his back, the patient presses his hand backward against resistance. The rhomboid muscle can be seen to contract.

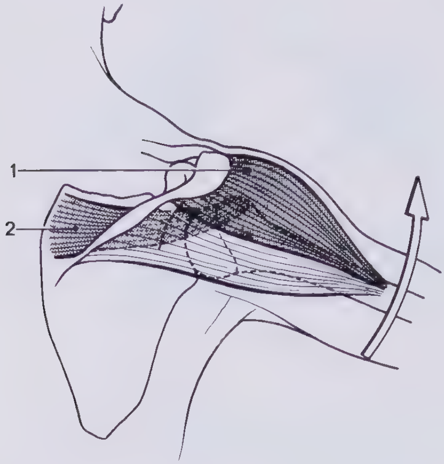


Figure 4–8. The abductors of the shoulder. 1, Middle part of deltoid. 2, Supraspinatus.

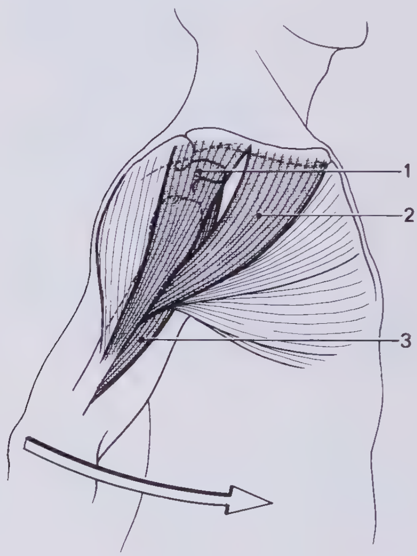


Figure 4–9. The flexors of the shoulder. 1, Anterior part of deltoid. 2, Clavicular head of pectoralis major. 3, Coracobrachialis.

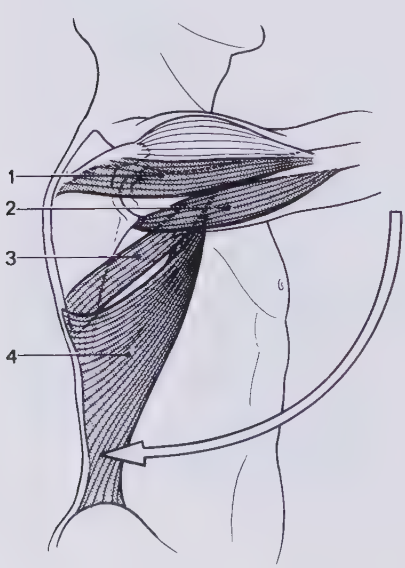


Figure 4–10. The extensors of the shoulder. 1, Posterior part of deltoid. 2, Long head of triceps. 3, Teres major. 4, Latissimus dorsi.

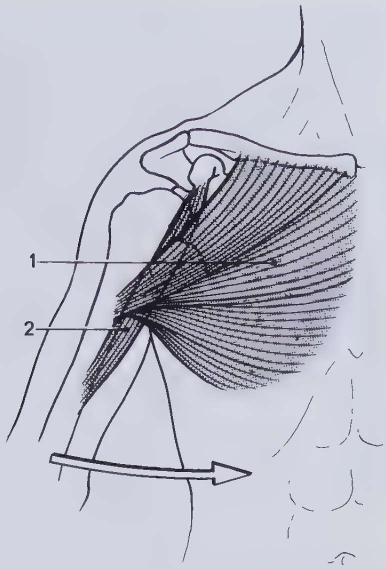


Figure 4–11. The adductors of the shoulder, anterior muscles. 1, Pectoralis major. 2, Coracobrachialis.

Adduction. Adduction is due to the combined action of anterior and posterior muscles—anteriorly, the pectoralis major and coracobrachialis and posteriorly, the posterior part of the deltoid, the long head of the triceps, the teres major, and the latissimus dorsi (Figs. 4–11, 4–12).

Medial Rotation. Medial rotation of the arm is brought about by the subscapularis, the teres major, the pectoralis major, and the latissimus dorsi (Fig. 4–13).

Lateral Rotation. Lateral rotation is achieved by the infraspinatus, the teres minor, and the posterior part of the deltoid.

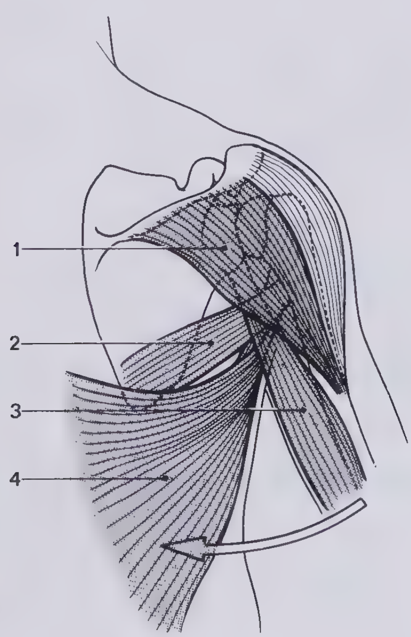


Figure 4–12. The adductors of the shoulder, posterior muscles. 1, Posterior part of deltoid. 2, Teres major. 3, Long head of triceps. 4, Latissimus dorsi.

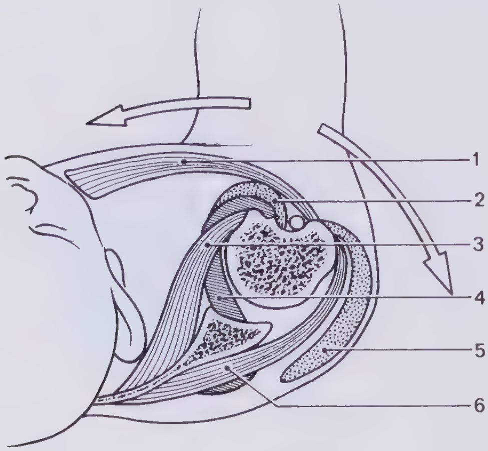


Figure 4–13. Medial and lateral rotators of the shoulder. Medial rotators: 1, Pectoralis major. 2, Latissimus dorsi. 3, Subscapularis. 4, Teres major. Lateral rotators: 5, Posterior part of deltoid. 6, Infraspinatus.

Pectoralis Major

Nerve supply: Lateral (C8, C7, C8) and medial (T1) pectoral nerves.

Action: Adducts, lowers, and medially rotates the arm.

Test of muscle function: The patient pulls his arm toward his chest against resistance (Fig. 4–14).

Pectoralis Minor

Nerve supply: Branches to the pectoralis minor (C8).

Action: Lowers the shoulder.

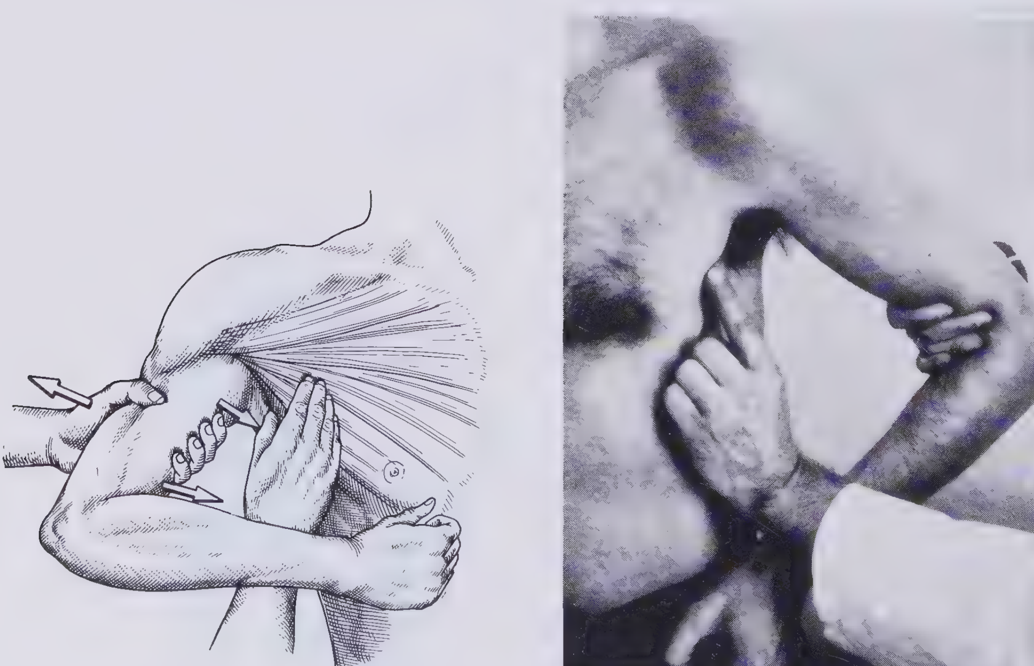


Figure 4–14. Pectoralis major. When the patient adducts his arm against resistance, the muscle belly can be seen and felt.

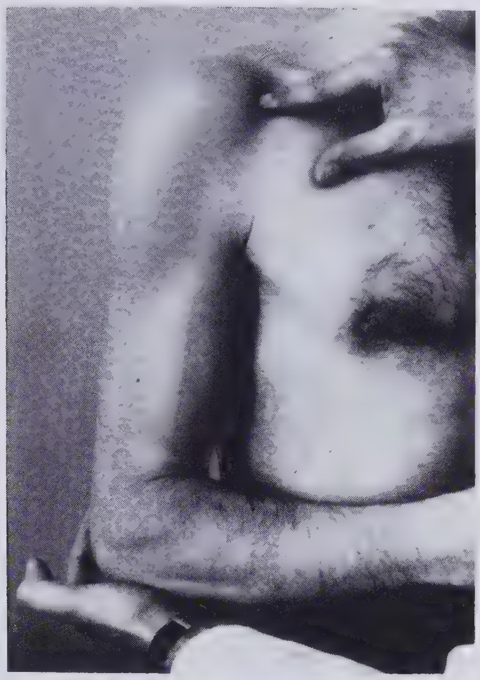


Figure 4–15. Pectoralis minor. The patient depresses his shoulder against resistance. The tendon can be felt at the coracoid process.

Test of muscle function: Lowering the shoulder against resistance; the tendon can be felt on the coracoid process (Fig. 4–15).

Latissimus Dorsi

Nerve supply: Thoracodorsal nerve from the posterior cord of C6, C7, and C8.

Action: Adductor, extensor, and medial rotator of the arm.

Test of muscle function: Adduction of the arm against resistance demonstrates the lateral border of the latissimus dorsi. The teres major contracts at the same time (Figs. 4–16, 4–17). Active adduction can be tested with the limb raised or lowered. Moberg (1978), remembering the name given to the muscle by ancient anatomists (musculus scapultor ani: "muscle used to scratch one's bottom"), asks the patient to carry his hand to his buttock against resistance applied by the examiner.

Deltoid

Nerve supply: Axillary nerve (C5, C6).

Action: Abductor of the arm. In addition the anterior fibers carry the arm forward and the posterior fibers carry it backward (Fig. 4–18*A* to *C*).

Test of muscle function:

1. Middle fibers: The patient is asked to abduct his arm against resistance, in the range of 15 to 90 degrees of abduction (Fig. 4–18*A, B*).
2. Anterior fibers: Elevation of the arm anteriorly against resistance (Fig. 4–18*C*).
3. Posterior fibers: Elevation of the arm posteriorly against resistance (Fig. 4–18*D*).

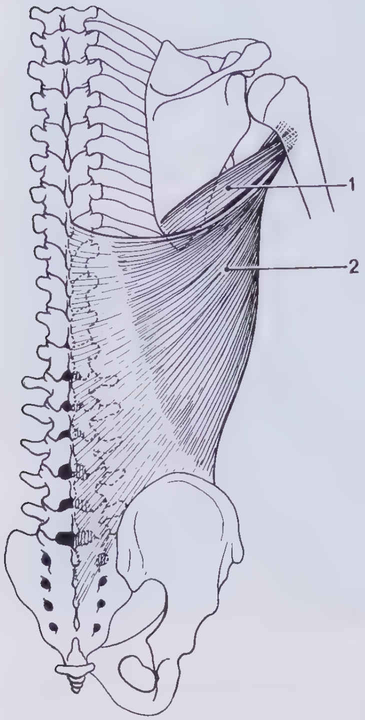


Figure 4–16. Anatomy of the teres major (1) and lattisimus dorsi (2).

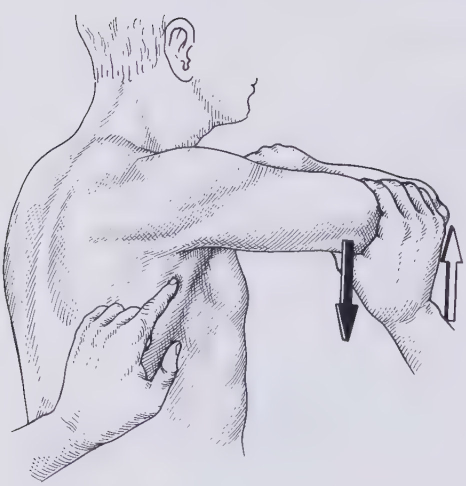
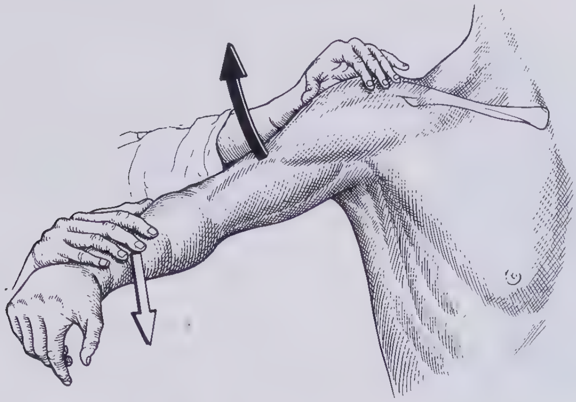
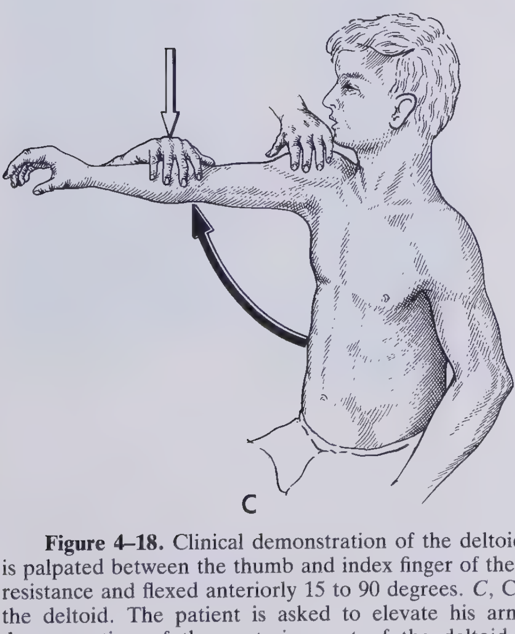


Figure 4–17. Clinical demonstration of the latissimus dorsi. The muscle can be seen when the patient adducts his arm against resistance.

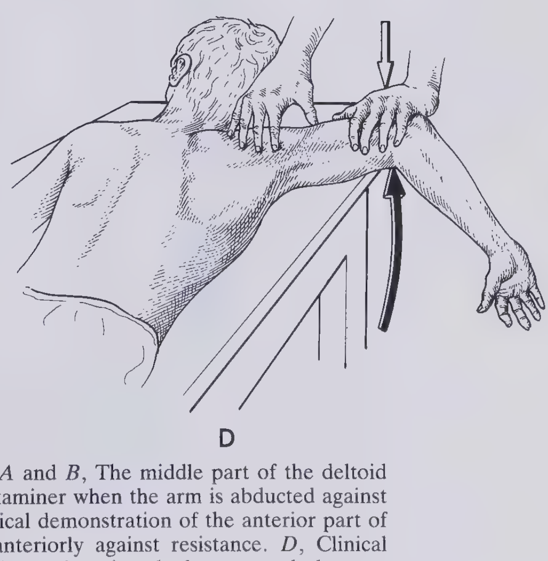


A

B



C



D

Figure 4–18. Clinical demonstration of the deltoid. *A* and *B*, The middle part of the deltoid is palpated between the thumb and index finger of the examiner when the arm is abducted against resistance and flexed anteriorly 15 to 90 degrees. *C*, Clinical demonstration of the anterior part of the deltoid. The patient is asked to elevate his arm anteriorly against resistance. *D*, Clinical demonstration of the posterior part of the deltoid. The patient is asked to extend the arm posteriorly at the shoulder against resistance.

Supraspinatus

Nerve supply: Suprascapular nerve (C5).
Action: Initiates abduction.
Test of muscle function: With the arm resting alongside the body, the patient attempts to abduct it against resistance. The muscle contraction normally can be felt under the upper part of the trapezius (Fig. 4–19).

Infraspinatus

Nerve supply: Suprascapular nerve (C5).
Action: Rotates the arm laterally (Fig. 4–20).
Test of muscle function: Standing up with his arm against his chest and the elbow in 90 degrees of flexion, the patient tries to carry his forearm laterally against resistance (Fig. 4–21*A*). Or, lying prone with his arm in 90 degrees of abduction and his forearm hanging down from the couch, the patient tries to externally rotate his arm against resistance (Fig. 4–21*B*).

Subscapularis

Nerve supply: Upper and lower branches of the scapular trunk, arising from the posterior division (C6, C7, C8; Fig. 4–22).
Action: Medial rotation of the arm, adduction.
Test of muscle function: The patient in the prone position (as for infraspinatus testing) tries to internally rotate his arm against resistance (Fig. 4–23).

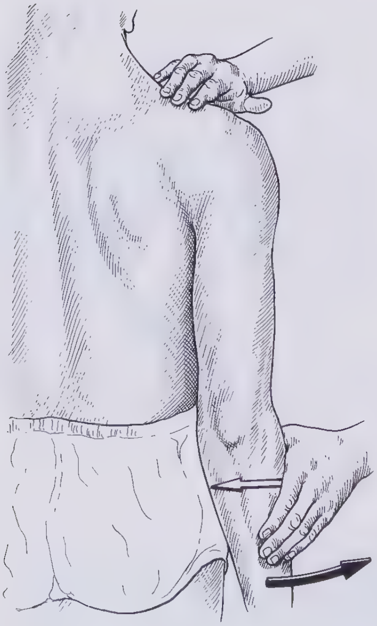


Figure 4–19. Clinical demonstration of the supraspinatus. As the patient abducts his arm against resistance, the muscle contraction can be felt.

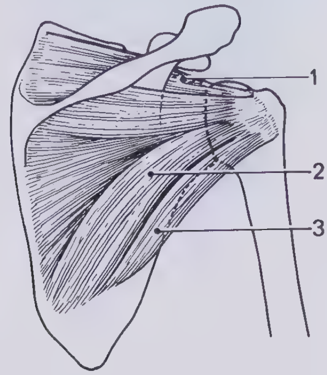


Figure 4–20. Anatomy of the supraspinatus (1), infraspinatus (2), and teres minor (3).

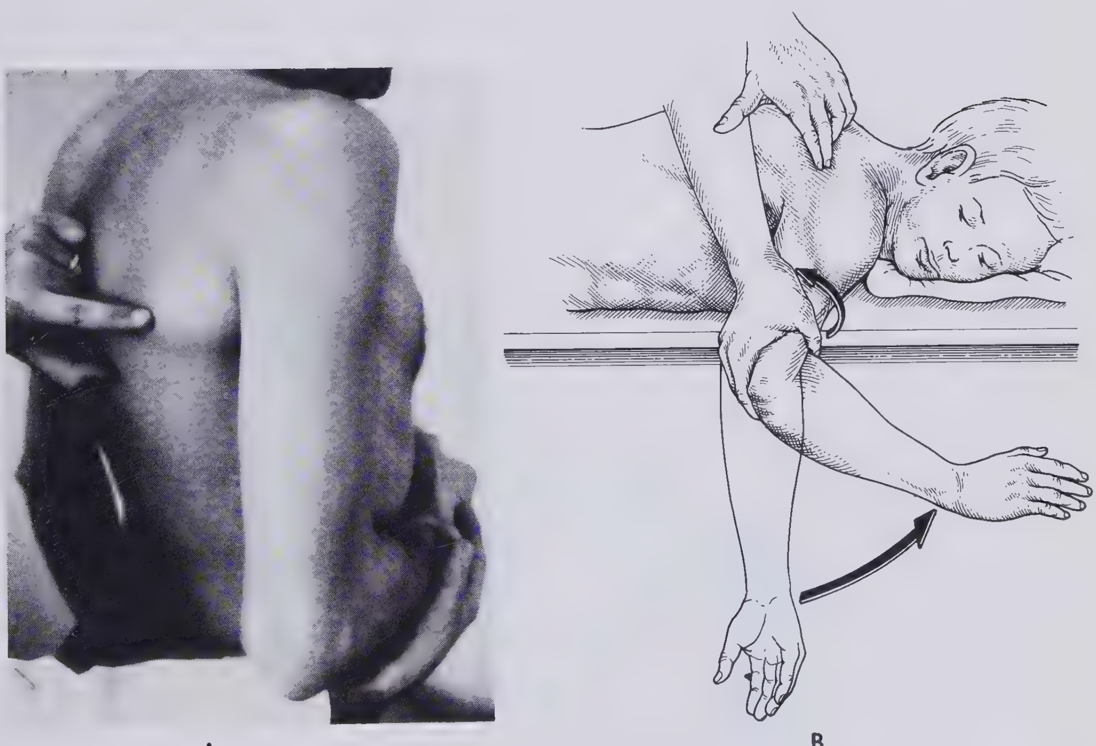


Figure 4–21. Clinical demonstration of the infraspinatus. *A*, The muscle can be palpated when the patient attempts to rotate the arm externally from the position of internal rotation. *B*, The patient lies prone with his shoulder abducted to 90 degrees, the elbow flexed to 90 degrees, and the forearm hanging down. The muscle can be palpated when he externally rotates the arm against resistance.

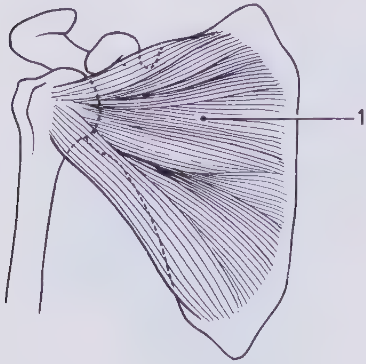


Figure 4–22. Anatomy of the subscapularis.

ANALYSIS OF MOVEMENTS OF THE ELBOW AND FOREARM

Elbow Flexion. Elbow flexion is brought about by biceps, the brachialis, the brachioradialis, and the pronator teres (Fig. 4–24).

Elbow Extension. Elbow extension is effected by the triceps and the anconeus (Fig. 4–25).

Forearm Pronation. Forearm pronation is effected by the pronator teres and the pronator quadratus (Fig. 4–26).

Forearm Supination. Forearm supination is effected by the biceps and the supinator (Fig. 4–27).

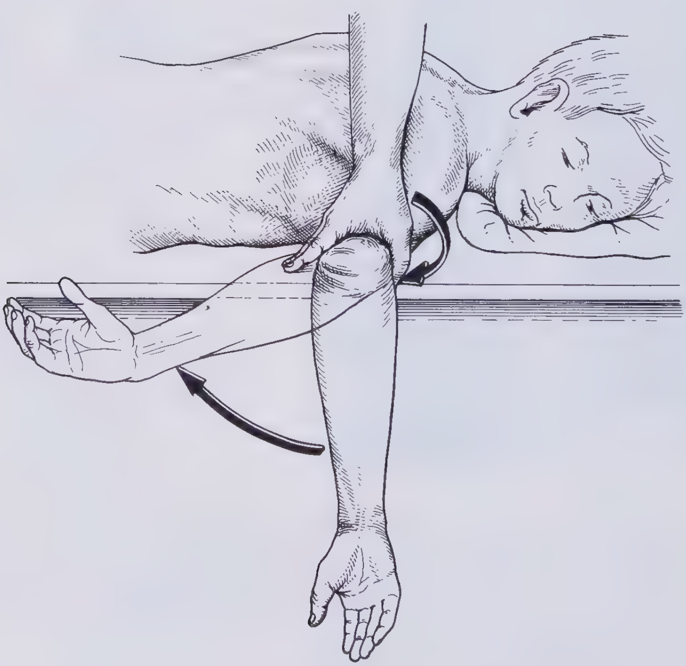


Figure 4–23. Clinical demonstration of the subscapularis. With the patient prone, the reverse procedure for testing the infraspinatus is performed.

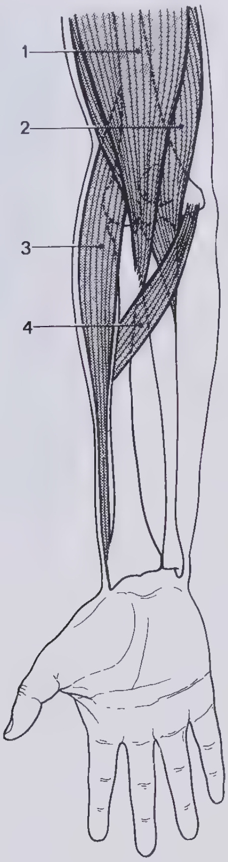


Figure 4–24. Flexors of the elbow. 1, Biceps. 2, Brachialis. 3, Brachioradialis. 4, Pronator teres.

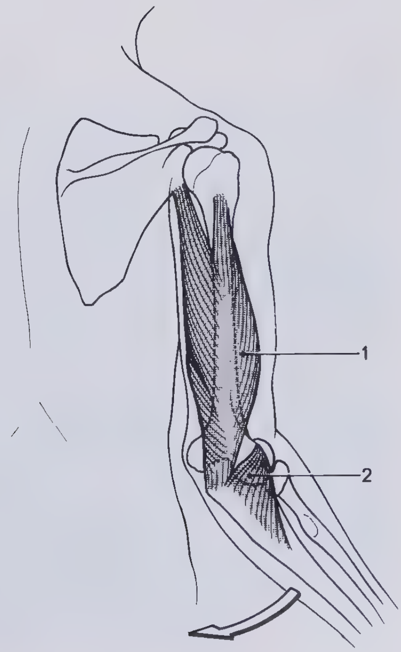


Figure 4–25. Extensors of the elbow. 1, Triceps. 2, Anconeus.

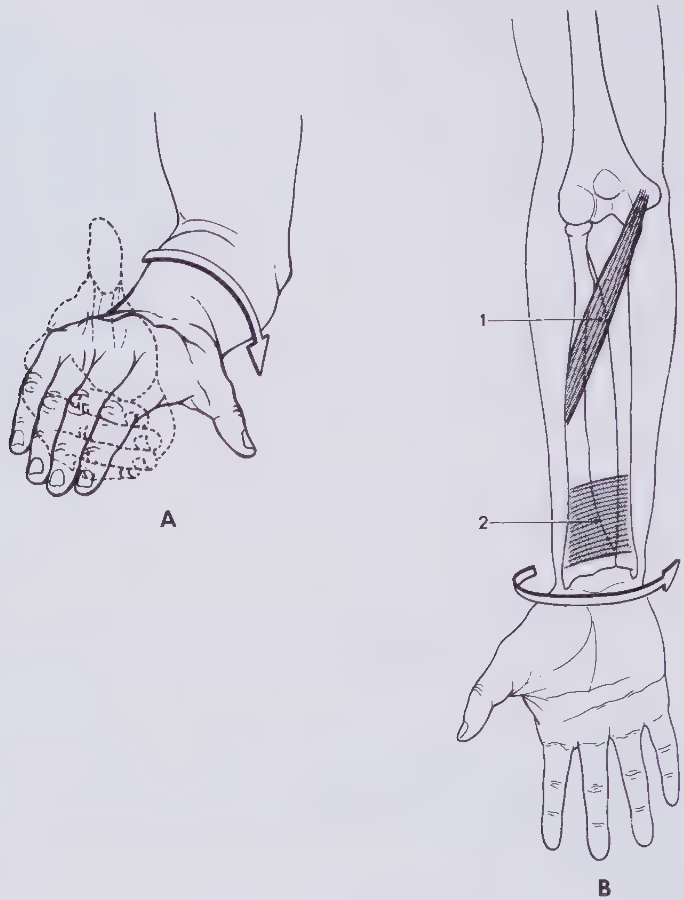


Figure 4–26. Pronation of the forearm. *A*, Movement of pronation. *B*, Muscles of pronation: 1, Pronator teres. 2, Pronator quadratus.

Biceps Brachii

Nerve supply: Musculocutaneous nerve (C5, C6).
Action: Flexes the elbow and supinates the forearm.
Test of muscle function: Flexion of the elbow against resistance with the forearm supinated (Figs. 4–28, 4–29).

Triceps

Nerve supply: Radial nerve (C5, C6, C7, C8).
Action: Extends the elbow; the long head also adducts the arm.
Test of muscle function: With the arm in 90 degrees of abduction, to eliminate the action of gravity, and the forearm hanging down, the patient tries to extend the elbow (Figs. 4–30, 4–31).

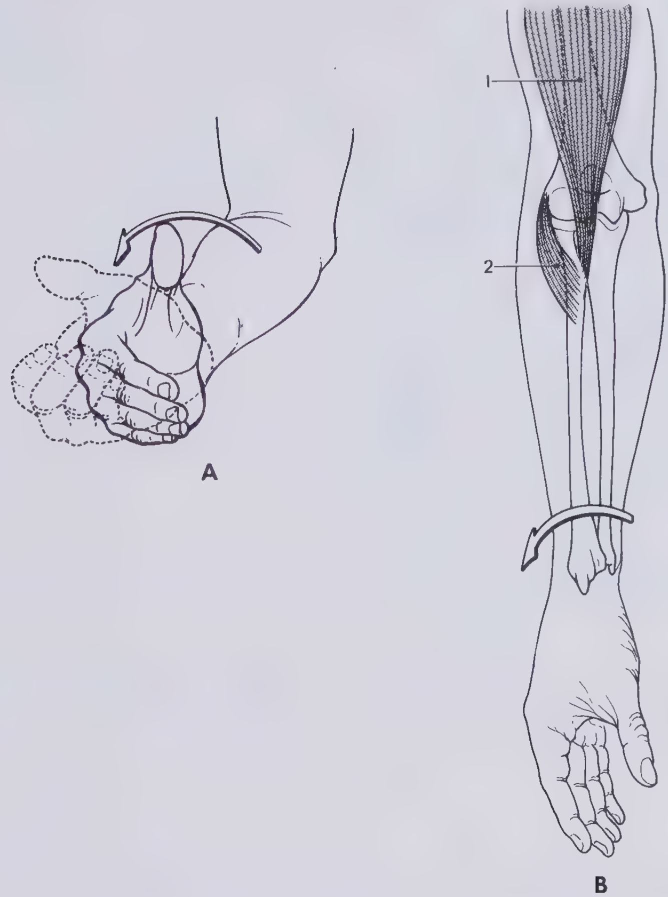


Figure 4–27. Supination of the forearm. *A*, Movement of supination. *B*, Muscles of supination: 1, Biceps. 2, Supinator.

Figure 4–28. Clinical demonstration of the biceps brachii by flexion of the elbow against resistance.

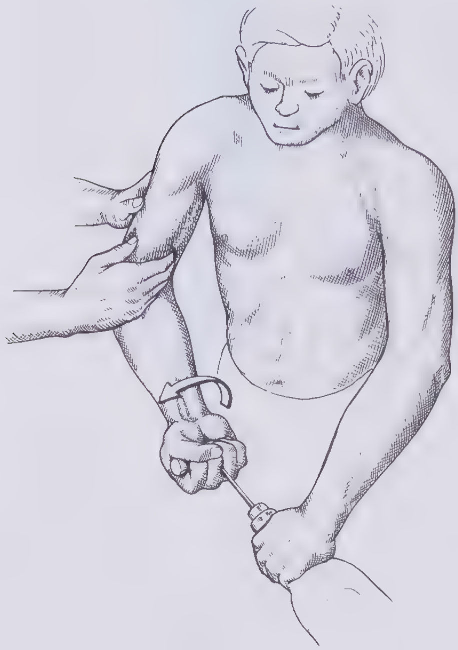


Figure 4–29. Clinical demonstration of the biceps brachii. Flexion of the elbow and supination, as in using a corkscrew, demonstrate the muscle.

Figure 4–30. Clinical demonstration of the triceps by use of resisted elbow extension.

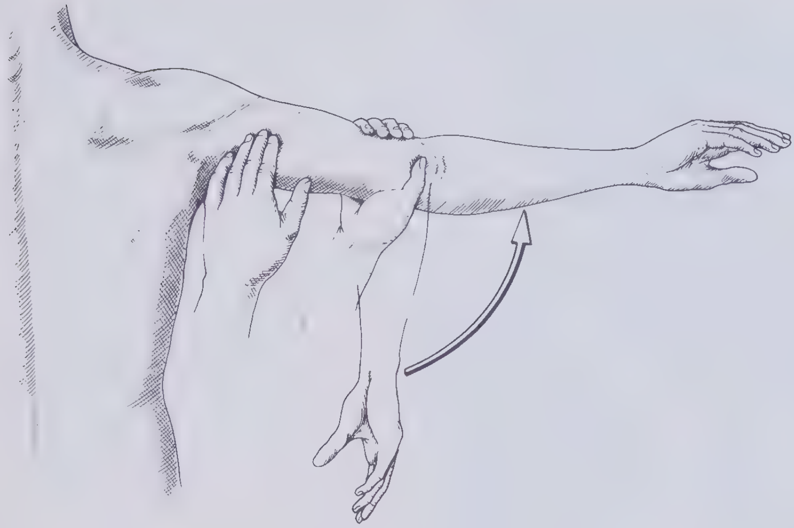


Figure 4–31. Clinical demonstration of the triceps. When testing the triceps, it is important to prevent trick movements that can extend the elbow by using gravity. The arm therefore should be placed horizontally to eliminate the effect of gravity.

Brachioradialis

Nerve supply: Radial nerve (C5, C6, C7).

Action: Flexes the elbow; also acts as a pronator in full supination and as a supinator in full pronation.

Test of muscle function: Flexion against resistance with the elbow in 90 degrees of flexion and the forearm halfway between pronation and supination (Fig. 4–32).

Figure 4–32. Clinical demonstration of the brachioradialis. Resisted elbow flexion is effected with the forearm in 90 degrees of flexion and neutral pronation and supination.

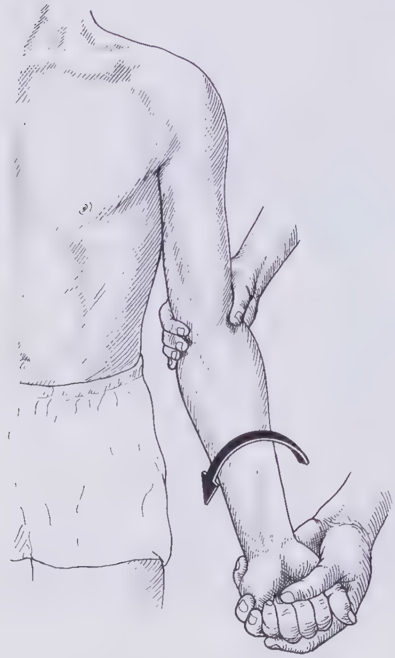


Figure 4–33. Clinical demonstration of the supinator. With the arm hanging by the side and the elbow extended to eliminate the action of biceps, the patient attempts to supinate the forearm against resistance.

Supinator

Nerve supply: Radial nerve (C5, C6).
Action: Supinates the forearm.
Test of muscle function: With the arm hanging and the elbow extended, the patient attempts to supinate the forearm against resistance (Fig. 4–33).

Pronator Teres

Nerve supply: Median nerve (C6, C7).
Action: Pronates the forearm, flexes the elbow.
Test of muscle function: With the elbow flexed, the patient pronates the forearm against resistance. Contraction of the muscle usually can be felt and seen (Fig. 4–34).

ANALYSIS OF MOVEMENTS OF THE WRIST

Wrist Flexion. Wrist flexion is brought about by the flexor carpi radialis, palmaris longus, and flexor carpi ulnaris.

Wrist Extension. Wrist extension is brought about by the extensor carpi radialis longus, extensor carpi radialis brevis, and extensor carpi ulnaris.

Radial Deviation. Radial deviation is brought about by the abductor pollicis longus, extensor carpi radialis longus and brevis, and flexor carpi radialis.

Ulnar Deviation. Ulnar deviation is brought about by the flexor carpi ulnaris and extensor carpi ulnaris.

Figure 4–34. Clinical demonstration of the pronator teres. With the elbow and fingers flexed, the patient attempts to pronate the forearm against resistance.

Flexor Carpi Radialis

Nerve supply: Median nerve (C6).
Action: Flexes the wrist.
Test of muscle function: Flexion of the wrist against resistance (Fig. 4–35).

Palmaris Longus

Nerve supply: Median nerve (C6).
Action: Flexes the wrist.
Test of muscle function: Flexion of the wrist against resistance (Fig. 4–35).

Flexor Carpi Ulnaris

Nerve supply: Ulnar nerve (C8, T1).
Action: Flexes the wrist with ulnar deviation.
Test of muscle function: Flexion and ulnar deviation of the wrist against resistance (Fig. 4–36).

Extensor Carpi Radialis Longus

Nerve supply: Radial nerve (C6, C7).
Action: Radial deviation and extension of the wrist.

Figure 4–35. Counterflexion of the wrist allows one to test the flexor carpi radialis and palmaris longus, for the tendons are accessible to direct examination.

Test of muscle function: Extends and deviates the wrist against resistance. The tendon is palpable over the base of the second metacarpal (Fig. 4–37).

Extensor Carpi Radialis Brevis

Nerve supply: Radial nerve (C6, C7).
Action: Extension of the wrist.
Test of muscle function: Extends the wrist against resistance. The tendon is palpable over the base of the third metacarpal (Fig. 4–38).

Extensor Carpi Ulnaris

Nerve supply: Radial nerve (C7).
Action: Extensor of the wrist in supination, ulnar deviation in pronation.

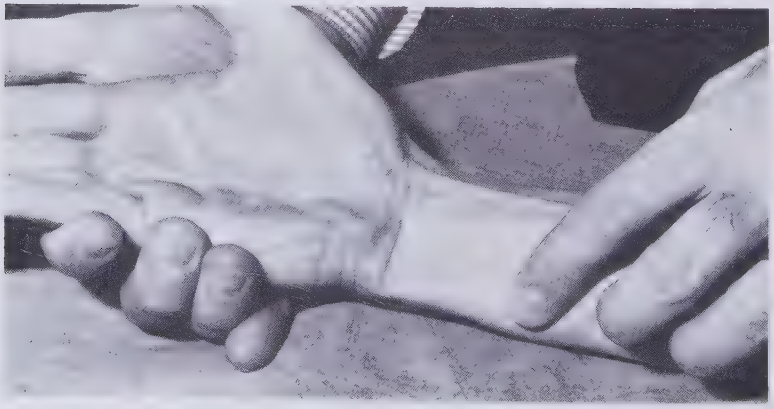


Figure 4–36. The flexor carpi ulnaris is evaluated by a movement counter to ulnar deviation and wrist flexion. Its tendon can be palpated at its insertion into the pisiform.

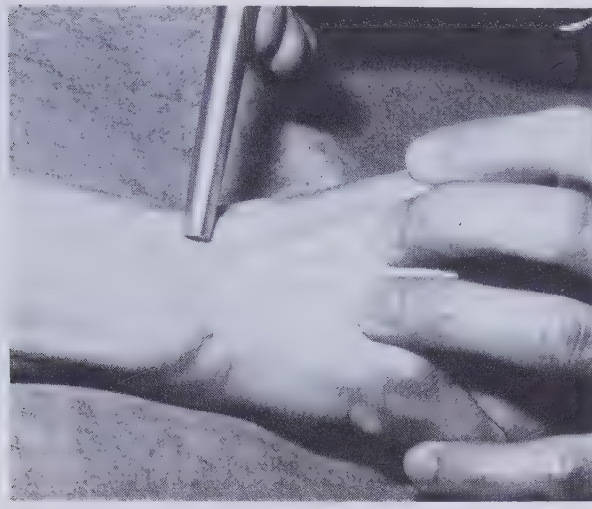


Figure 4–37. Isolated contraction of the extensor carpi radialis longus effects radial deviation of the hand when the wrist is extended. Its tendon is palpable over the base of the second metacarpal.

Test of muscle function: Ulnar deviation of the wrist against resistance in pronation. The tendon is palpable over the base of the fifth metacarpal (Fig. 4–39).

ANALYSIS OF THE MOVEMENTS OF THE FINGERS

Finger Flexion. Finger flexion is brought about by the flexor digitorum superficialis, flexor digitorum profundus, and the interosseous muscles.

Finger Extension. Finger extension is brought about by the extensor digitorum communis, extensor indicis proprius, extensor digiti quinti proprius, and the interosseous and lumbrical muscles.

Figure 4–38. Only the extensor carpi radialis brevis is able by itself to effect direct extension of the wrist. Its tendon is palpable over the base of the third metacarpal.

Figure 4–39. The extensor carpi ulnaris is evaluated by counterextension and ulnar deviation of the wrist. Its tendon can be felt at its insertion on the fifth metacarpal.

Finger Abduction. Finger abduction is brought about by the dorsal interosseous muscles and the abductor digiti quinti.

Finger Adduction. Finger adduction is brought about by the palmar interosseous muscles.

Flexor Digitorum Superficialis

Nerve supply: Median nerve (C7, C8, T1).

Action: Flexion of the proximal interphalangeal joint.

Test of muscle function: Active flexion of the proximal interphalangeal joint of one finger while all the other fingers are held in full extension (Figs. 4–40, 4–41).

Flexor Digitorum Profundus

Nerve supply: Median nerve (volar interosseous branch; C8, T1) for the index and long fingers; ulnar nerve (C8, T1) for the ring and little fingers.

Figure 4–40. Testing the flexor digitorum superficialis. (See text.)

Figure 4–41. By putting all the fingers except the finger to be examined into passive extension, the flexor superficialis over-rides the action of its deep flexor. The flaccidity of the distal phalanx, which is put into hyperextension, verifies this absence of contracture of the profundus flexor.

Action: Flexion of the distal interphalangeal joint.

Test of muscle function: Flexion of the distal phalanx; the two proximal phalanges are held in extension (Figs. 4–42, 4–43).

Extensor Digitorum Communis

Nerve supply: Radial nerve (C7).

Action: Active extension of the metacarpophalangeal joints of the fingers.

Test of muscle function: Extension of the proximal phalanx against resistance (Fig. 4–44).

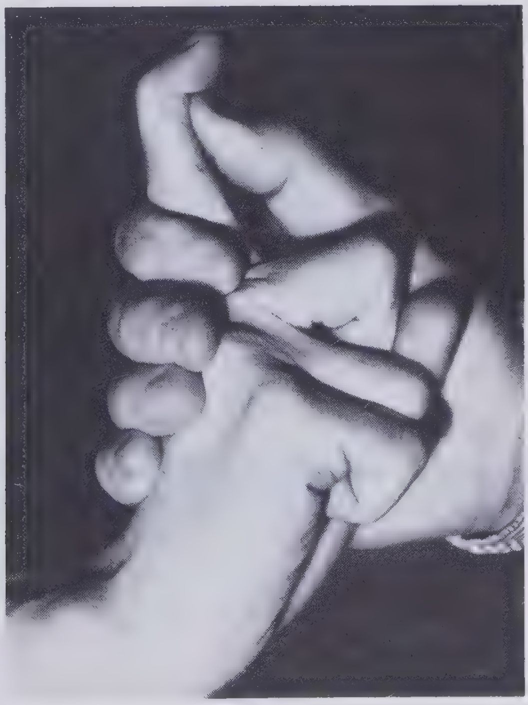


Figure 4–42. The flexor profundus flexes the distal phalanx. If the wrist and the two proximal joints of a finger are put into extension, and the muscle body is kept on tension, contractions of small amplitude can be detected.

Figure 4–43. The strength of the flexor profundus is evaluated by applying counterpressure to the pulp on the flexed fingers.

Figure 4–44. Evaluation of the extensor muscle. Passive dorsiflexion of the wrist excludes automatic metacarpophalangeal extension by a tenodesis effect; resistance is applied to the dorsal aspect of the proximal phalanx.

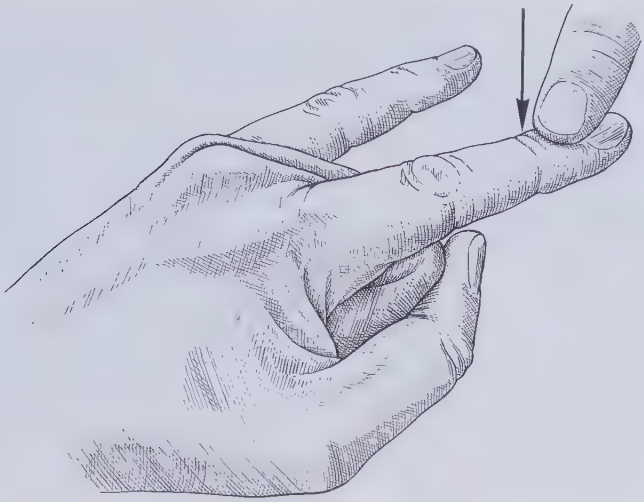


Figure 4–45. Testing the extensor indicis proprius. (See text.)

Extensor Indicis Proprius

Nerve supply: Radial nerve (C7).

Action: Extension of the metacarpophalangeal joint of the index finger.

Test of muscle function: With the metacarpophalangeal joints of the long and ring fingers completely flexed to eliminate the action of the extensor communis, the proximal phalanx of the index finger is extended against resistance (Fig. 4–45).

Extensor Digiti Quinti Proprius

Nerve supply: Radial nerve (C7).

Action: Extension of the metacarpophalangeal joint of the little finger.

Test of muscle function: With the metacarpophalangeal joints of the long and ring fingers completely flexed, the proximal phalanx of the little finger is extended against resistance (Fig. 4–45).

Interosseous Muscles

Nerve supply: Ulnar nerve (C8).

Action: The interosseous muscles as a group flex the metacarpophalangeal joints and extend the proximal and distal interphalangeal joints. The dorsal interosseous muscles abduct the index, ring, and little fingers away from the long finger. The palmar interosseous muscles are adductors.

Test of muscle function: Side to side movements of the fingers are partly dependent on the action of the extrinsic muscles. Each finger is tested separately with the metacarpophalangeal joint extended (Figs. 4–46 to 4–49).

Figure 4–46. The interosseous muscles alone are capable of flexing the metacarpophalangeal joints simultaneously, with extension of the interphalangeal joints. This is the intrinsic-plus position.

Abductor Digiti Minimi

Nerve supply: Ulnar nerve (C8).
Action: Abducts the little finger and flexes the metacarpophalangeal joint.
Test of muscle function: Abduction of the little finger against resistance (Fig. 4–50).

Opponens Digiti Minimi

Nerve supply: Ulnar nerve (C8).
Action: Flexion of the fifth metacarpal.
Test of muscle function: Flexion of the fifth metacarpal against resistance (Fig. 4–51).

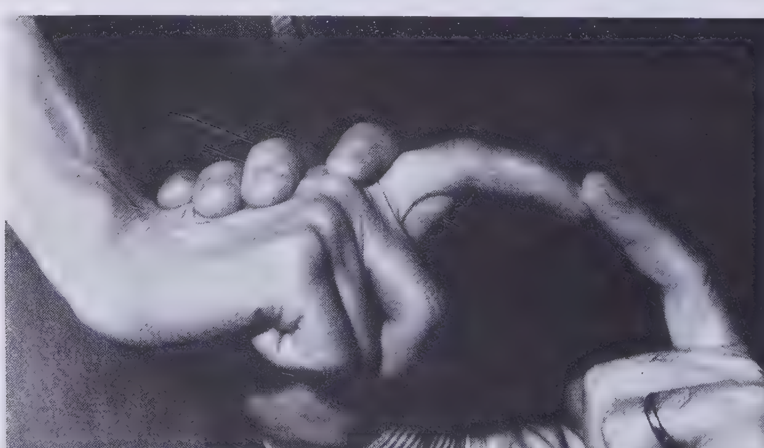


Figure 4–47. By putting the metacarpophalangeal joints into extension first, one can demonstrate a contracture of the interosseous muscles of the corresponding finger, which keeps the interphalangeal joints extended.

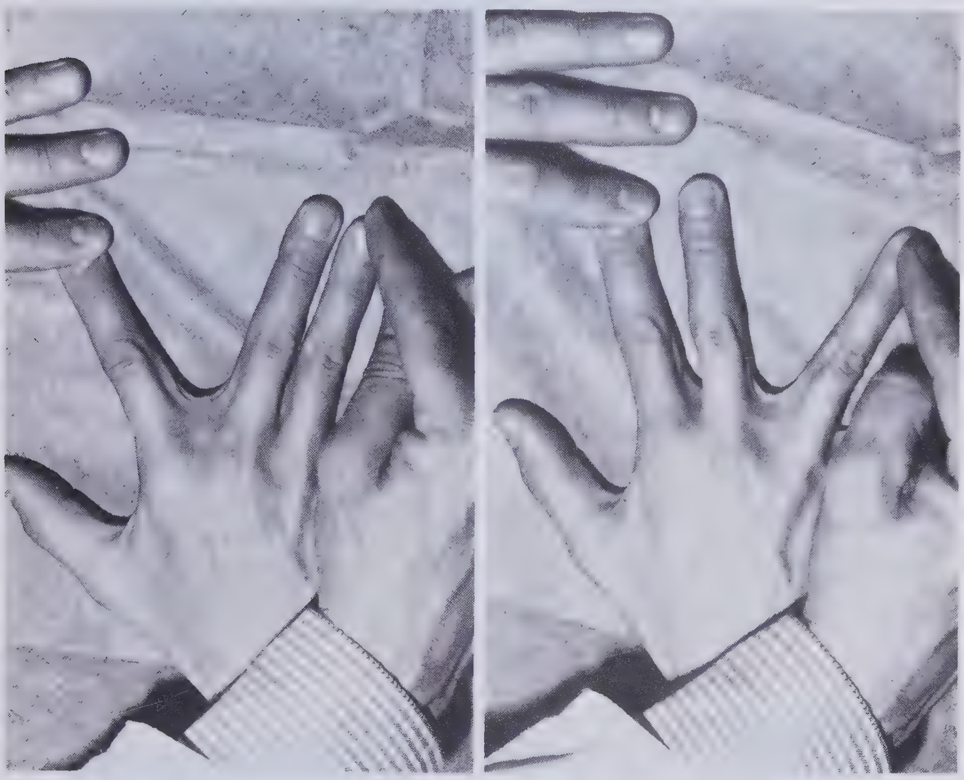


Figure 4–48. The amplitude and precision of voluntary movements of radial deviation of each finger show the quality of innervation of the corresponding interosseous muscles.

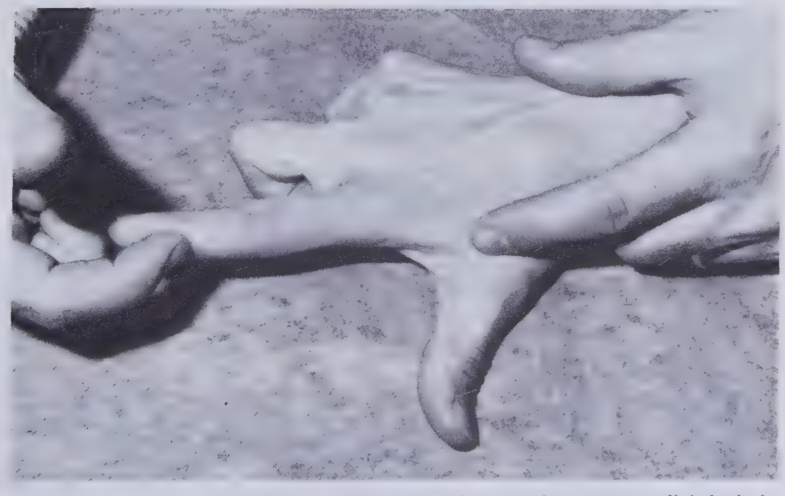


Figure 4–49. The first dorsal interosseous muscle effects active strong radial deviation of the index finger. The muscle belly is palpable; its strength is evaluated by applying counterpressure to the radial side of the finger.

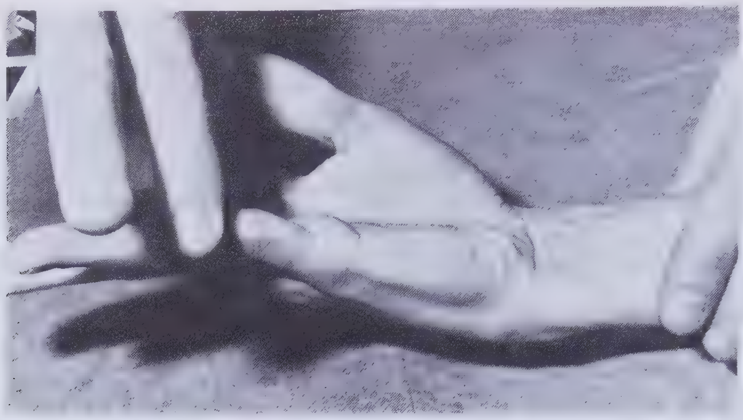


Figure 4–50. The abductor effects strong ulnar deviation of the finger. The contraction of its muscle belly is visible, and its strength can be evaluated by applying counterpressure on the ulnar border of the proximal phalanx.

Flexor Digiti Minimi

Nerve supply: Ulnar nerve (C8).
Action: Abduction of the little finger. Cannot be tested specifically.

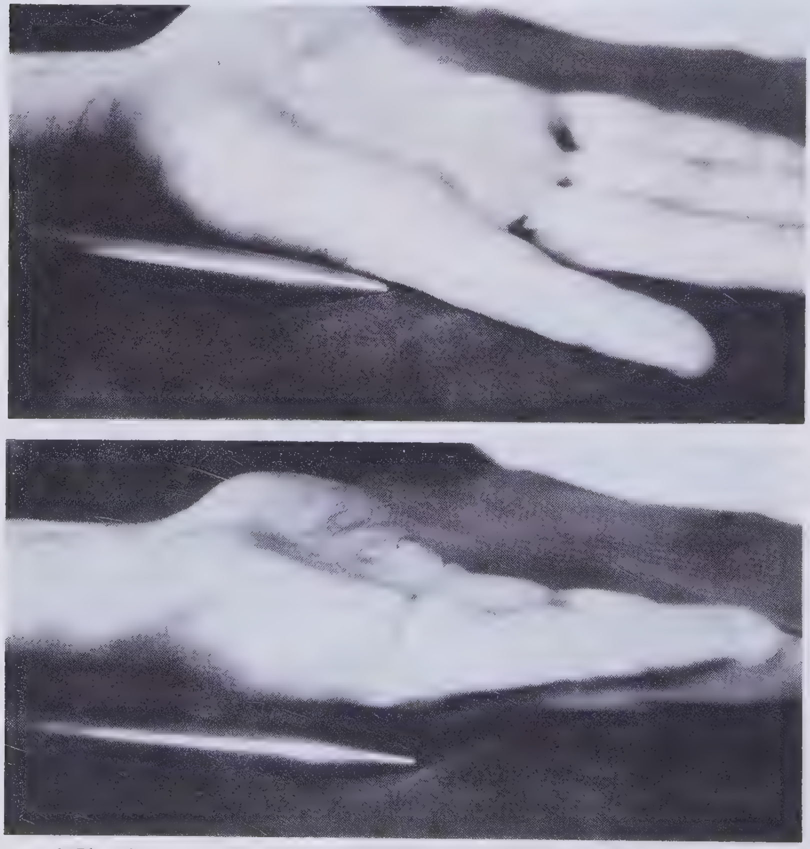


Figure 4–51. The opponens digiti minimi performs active flexion of the fifth metacarpal. Palmar counterpressure on its head can be used to evaluate its strength.

ANALYSIS OF THE MOVEMENTS OF THE THUMB

Flexion. Flexion is produced by the flexor pollicis longus and the flexor pollicis brevis.

Extension. Extension is produced by the extensor pollicis longus and extensor pollicis brevis.

Pronation. Pronation is produced by the abductor pollicis brevis and flexor pollicis brevis.

Supination. Supination is produced by the adductor pollicis and extensor pollicis longus.

ANALYSIS OF THE MOVEMENTS OF THE FIRST METACARPAL

Anteposition. Anteposition is produced by the abductor pollicis brevis and opponens pollicis.

Retroposition. Retroposition is produced by the extensor pollicis longus.

Flexion-Adduction. Flexion-adduction is produced by the adductor pollicis and flexor pollicis brevis.

Extension-Abduction. Extension-abduction is produced by the abductor pollicis longus.

Opposition. Opposition is a combined movement involving all three segments of the thumb column: the first metacarpal moves in anteposition and then in flexion-adduction. This movement is accompanied by an "automatic" longitudinal rotation into pronation. The proximal phalanx flexes, pronates, and radially deviates. The distal phalanx flexes and slightly pronates (see Figure 1–72, page 68).

Flexor Pollicis Longus

Nerve supply: Median nerve (C8, T1).

Action: Flexion of the interphalangeal joint of the thumb.

Test of muscle function: Flexion of the distal phalanx of the thumb against resistance (Fig. 4–52).

Extensor Pollicis Longus

Nerve supply: Radial nerve (C7).

Action: Extension of the interphalangeal joint and of the metacarpophalangeal joint of the thumb as well as retroposition, adduction, and supination of the thumb column.

Test of muscle function: Retroposition of the thumb column (Fig. 4–53).

Extensor Pollicis Brevis

Nerve supply: Radial nerve (C7).

Action: Extension of the metacarpophalangeal joint of the thumb.

Test of muscle function: Extension of the proximal phalanx with the distal phalanx semiflexed (Fig. 4–54).

Figure 4–52. Flexion of the interphalangeal joint of the thumb against resistance applied to the pulp makes it possible to evaluate the strength of the flexor pollicis longus.

Abductor Pollicis Longus

Nerve supply: Radial nerve (C7).

Action: Radial abduction of the thumb column.

Test of muscle function: The patient is asked to move his thumb in radial abduction; the tension of the tendon is felt on the extensor border of the anatomical snuffbox (Fig. 4–55).

Figure 4–53. Only the extensor pollicis longus is capable of effecting active retropulsion of the column of the thumb and active interphalangeal hyperextension of the thumb.

Figure 4–54. Extension of the metacarpophalangeal joint of the thumb simultaneously brings into play the short and long extensors.. Evaluation of the short extensor by counterpressure on the dorsal aspect of the proximal phalanx is not as reliable as when the interphalangeal joint is semiflexed.

Abductor Pollicis Brevis

Nerve supply: Median nerve (C6, C7).

Action: Anteposition of the thumb column in the plane perpendicular to the palm as well as lateral deviation and pronation of the proximal phalanx.

Test of muscle function: Anteposition of the thumb against resistance (Fig. 4–56).

Opponens Pollicis

Nerve supply: Median nerve (C6, C7).

Action: Anteposition of the first metacarpal.

Test of muscle function: Direct palpation of the muscle during anteposition of the thumb against resistance (Fig. 4–57).

Flexor Pollicis Brevis

Nerve supply: Median nerve (C6, C7) for the superficial portion; ulnar nerve (C8) for the deep portion.

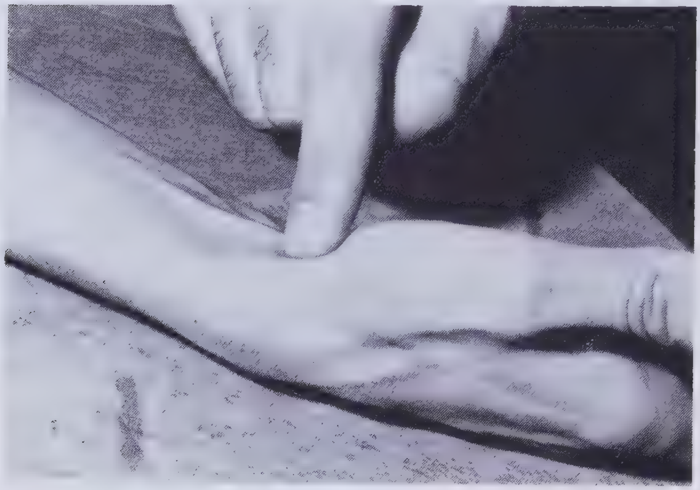
Action: Flexion of the metacarpophalangeal joint of the thumb as well as flexion-adduction and pronation of the thumb column.

Test of muscle function: Difficult to demonstrate unless the other thenar muscles are paralyzed.

Adductor Pollicis

Nerve supply: Ulnar nerve (C8).

Action: Approximation of the first to the second metacarpal, flexion-



A

B

Figure 4–55. *A*, Tension in the abductor pollicis longus palpable at the anterior border of the snuffbox is perceptable at the beginning of antepulsion, before the short abductor comes into play. *B*, Separation of the thumb in the plane of the palm is effected by the abductor pollicis longus and extensor pollicis brevis.

Figure 4–56. The abductor pollicis brevis performs antepulsion of the column of the thumb accompanied by pronation and ulnar deviation. Its strength can be evaluated by applying resistance to the radial aspect of the proximal phalanx.

adduction and supination of the thumb column, and extension of the distal phalanx.

Test of muscle function: Approximation of the first and second metacarpals, without flexing the thumb (to eliminate the flexor pollicis longus action) and the wrist extended (to relax the extensor pollicis longus; Figs. 4–58, 4–59).

DIFFICULTIES IN TESTING VOLUNTARY MOVEMENTS

Errors of interpretation can have serious consequences. They are due to associated lesions, compensatory movements, and trick movements.

Associated Lesions. Associated traumatic or post-traumatic lesions not involving nerves, such as tendon divisions, bone and joint injuries, adhesions, and stiffness, can interfere with muscle movements.

Figure 4–57. The contraction of the muscle belly of the opponens is perceptable in the pulp-to-pulp opposition of the thumb against the little finger.

Figure 4–58. When the thumb is forced against the index finger, compensatory flexion of the interphalangeal joint is a sign of weakness of the adductor muscle of the thumb (Froment's sign).

Compensatory Movements. One must always remember that no muscle functions in isolation and that the simplest movements require the participation of several muscles (which may well be supplied by different nerve roots). The prime movers, which initiate the movement, are assisted by synergists and

A B

Figure 4–59. The strength of active closure of the first commissure (*A*) is evaluated by trying to separate the first and second metacarpals, held voluntarily closed. However, the long muscles of the thumb participate in this adduction. *B*, Participation of the adductor pollicis in closure of the commissure can be verified by direct palpation of the transverse fibers during thumb-index finger pinch.

checked by antagonists and stabilizers. The final movement results from the modulation of these various forces.

The examiner should always take into account possible muscle "compensation." A muscle may have a secondary action, which is usually masked and becomes evident only when the adjacent muscles are paralyzed. Thus, the brachioradialis by itself can flex the elbow when the biceps and brachialis are paralyzed; the extensor digitorum communis can extend the interphalangeal joints if the interosseous muscles are paralyzed, provided the metacarpophalangeal joints are stabilized and hyperextension is prevented (Fig. 4–60). The dorsal expansions of the thenar muscles can extend the distal phalanx of the thumb in paralysis of the extensor pollicis longus, and the abductor pollicis longus can flex the wrist when the flexors are paralyzed.

Deceptive or Trick Movements. Trick movements have a number of causes, one of which is the effect of gravity (Jones, 1919). For example, when one is testing the function of the triceps muscle, the shoulder should be abducted to 90 degrees and internally rotated; thus the muscle can be tested with gravity eliminated. Gravity itself will cause extension of the elbow, even when the triceps is paralyzed, in certain positions of the arm.

Moreover, sudden relaxation of a contracting muscle whose antagonist is paralyzed can stimulate movement in the latter; this is seen in paralysis of the long flexors of the fingers when sudden relaxation of the extensors triggers passive flexion of the metacarpophalangeal joint. In a multiarticular kinetic chain, such as the hand, the extrinsic tendons of the fingers cross several joints. Movements of the proximal joint, e.g., the wrist, can have a tenodesis effect and produce movements of the phalanges. Conversely, in radial palsy, flexion of the fingers can extend the wrist.

The commonest sources of error, however, are anomalous innervation and variations in the territories of nerve supply. Such variations are seen most often with the flexor digitorum profundus communis and with the thenar muscles. The territories can be differentiated only by means of selective trunk anesthesia (Highet, 1942).

Figure 4–60. In cases of interosseous muscle palsy, stabilization and prevention of hyperextension of the metacarpophalangeal joints allow the extensor digitorum to extend the interphalangeal joints.

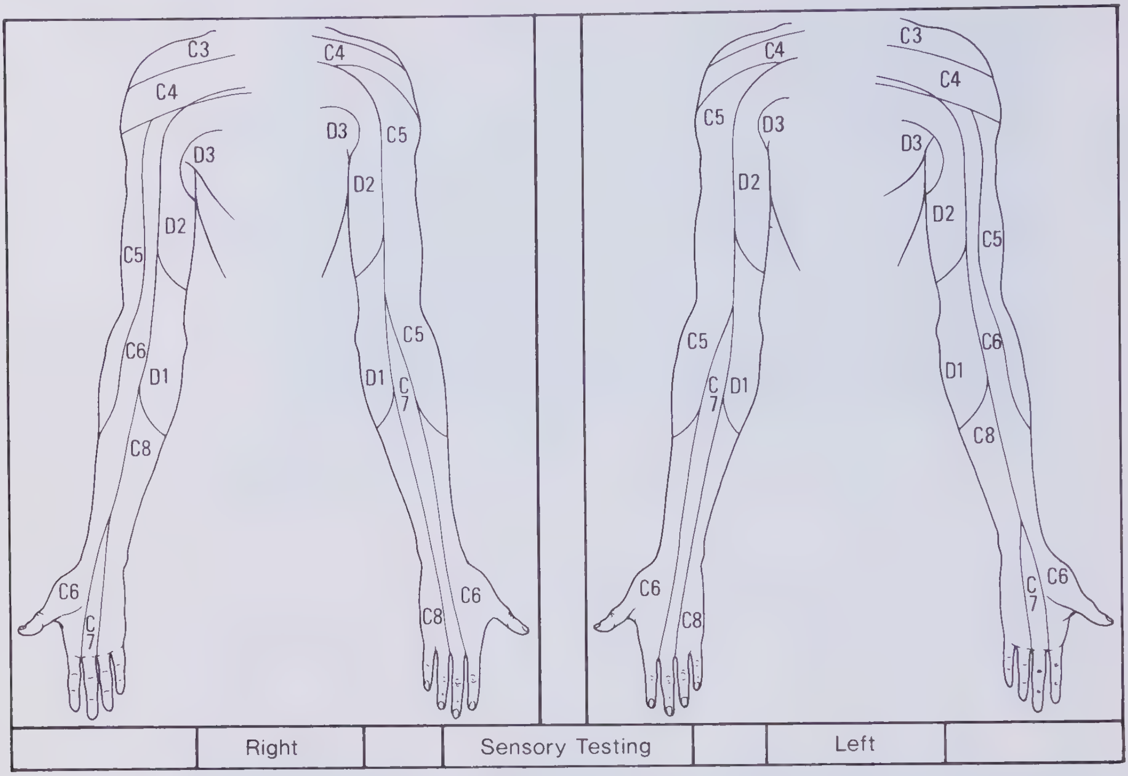


Figure 4–61. Chart for sensory testing.

TESTING SENSORY FUNCTION

Testing sensation is an essential part of the examination of the hand. The normal cutaneous sensory distribution of the nerve roots and the individual peripheral nerves are shown in Figures 4–61 and 4–62. Sensory skin territories have ill defined boundaries, and adjacent territories overlap extensively. Thus, sectioning of the radial nerve may produce little to no clinically detectable anesthesia on the dorsum of the hand. The so-called "autonomous" zone of skin supply is much smaller than its potential sensory territory.

The methods of examination of sensibility are discussed in Chapter 5. The various techniques in current use can be grouped into three categories:

SUBJECTIVE TESTS

Subjective tests requiring full cooperation of the patient test for touch, pain, and temperature (pin prick, cotton wool, von Frey's hairs).

After each examination one should draw on a chart the area of sensory loss. The persistence of complete anesthesia is one of the major signs indicating complete nerve division. By contrast, in the early stages of nerve compression, the area of altered cutaneous sensation may vary from day to day (Dejerine, 1944). During nerve recovery there is a concentric diminution in the area of sensory loss.

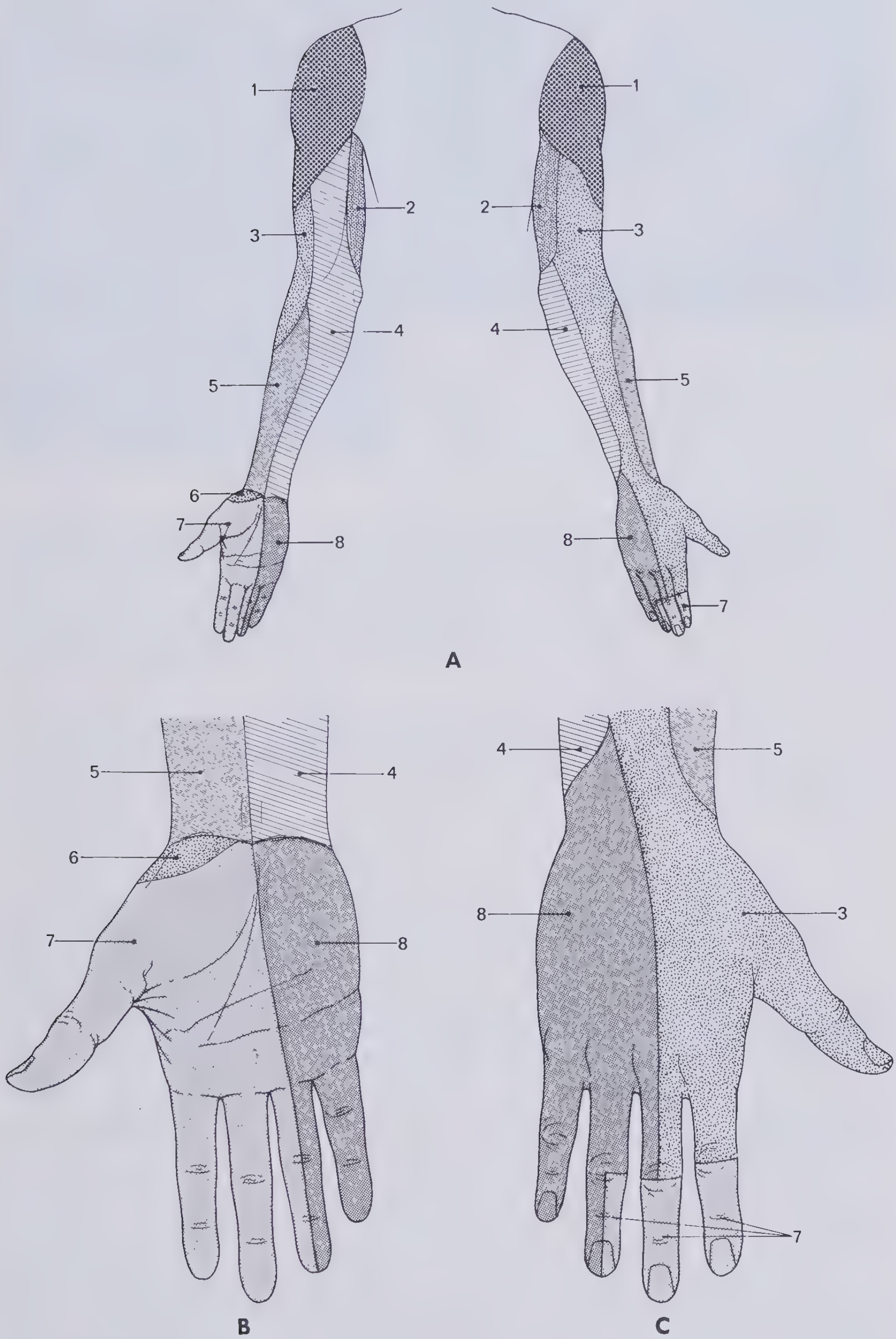


Figure 4–62. *A*, Cutaneous sensory distribution of the peripheral nerves of the upper limb. *B*, Volar aspect of the hand. *C*, Dorsal aspect of the hand. 1, Axillary nerve. 2, Intercostobrachial nerve. 3, Radial nerve. 4, Medial cutaneous nerve of forearm and arm. 5, Lateral cutaneous nerve of forearm (musculocutaneous nerve). 6, Palmar cutaneous branch of radial nerve. 7, Median nerve. 8, Ulnar nerve. There is a considerable variation in the cutaneous areas supplied by each nerve.

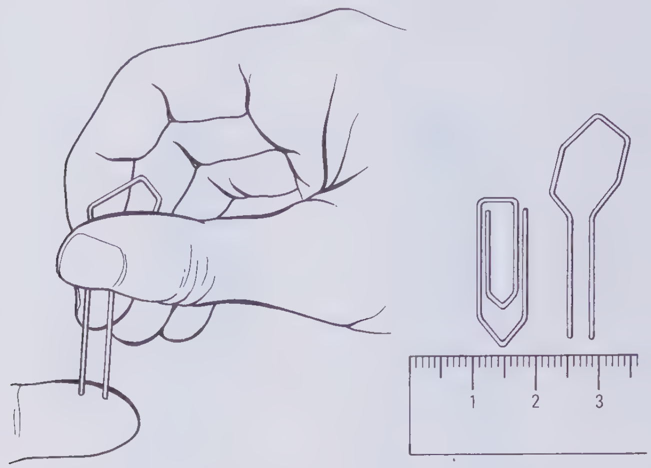


Figure 4–63. Technique of the Weber two point discrimination test. (After Moberg, 1958.)

OBJECTIVE TESTS

Objective tests requiring no active participation of the patient include the sweat tests, such as the starch and iodine method modernized by Önne (1962), the quinizarine method of Guttmann (1940), and the Ninhydrin test of Moberg (1958). In the wrinkled finger test of O'Riain (1973) the hand is immersed in hot water at 40° C. for 20 to 30 minutes; normal finger pulps wrinkle whereas denervated pulps remain smooth.

These examination techniques outline objectively the affected territory. However, they give no information about the functional value of the hand as a sensory organ.

FUNCTIONAL TESTS

Moberg has carried out extensive studies of the functional sensibility of the hand. He attaches great value to Weber's two point discrimination test (see also p. 177). This test, although it requires the patient's cooperation, provides objective data that can be quantified. These measurements are certainly useful, provided the technique is very precise. Because the different areas of the skin of the hand normally present regional variations in sensibility, it is recommended that the corresponding areas of both hands be compared (Fig. 4–63; see also p. 189).

However, a number of reports have indicated that many individuals can acquire good discriminative sensitivity despite the persistence of two point discrimination of more than 20 mm. (Onne, 1962). In the opinion of Wynn Parry (1981) this is because the static two point discrimination test measures essentially the reinnervation of slowly adapting receptors, whereas the rapidly adapting receptors are the first to be reinnervated. The two point test provides incomplete information concerning functional sensitivity, since the latter is in fact dependent upon temporally and spatially dynamic movement patterns. The most reliable tests for the study of tactile sensation are dynamic tests that explore the ability of a subject to recognize objects or textures between the moving fingers, e.g., the Moberg "pick-up" test (Fig. 4–68; see also p. 180) and the "ridge test" devised by Renfrew (1960).

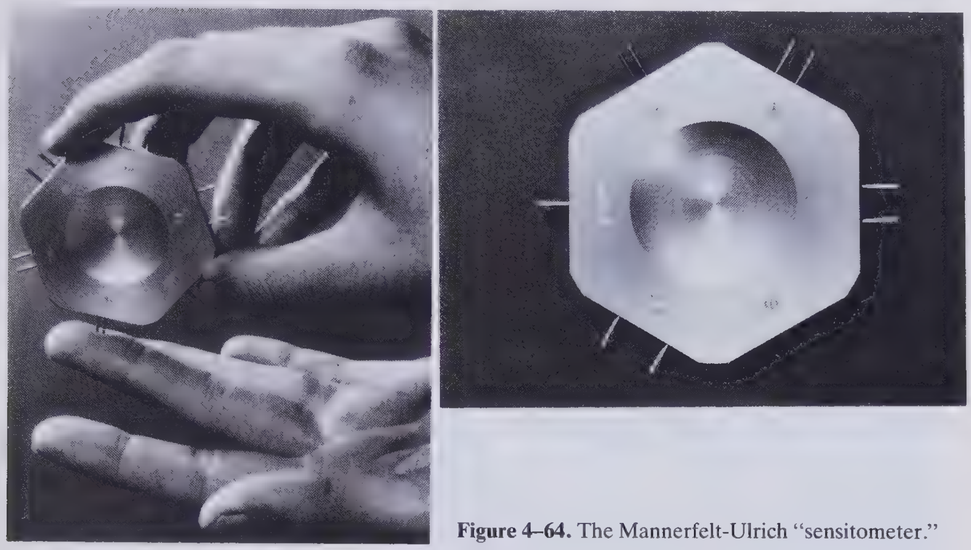


Figure 4–64. The Mannerfelt-Ulrich "sensitometer."

Scales for the assessment of sensibility, more or less similar to the motor scales, are based mainly on the British Medical Research Council scale (Seddon, 1975).

SENSORY RECOVERY

S0—Absence of sensibility in the autonomous area.

S1—Recovery of deep cutaneous pain sensibility within the autonomous area of the nerve.

S2—Return of some degree of superficial cutaneous pain and tacile sensibility within the autonomous area of the nerve.

S3—Return of superficial cutaneous pain and tactile sensibility throughout the autonomous area, with disappearance of any previous over-response.

S3+—Return of sensibility as in stage 3, with some recovery of two point discrimination within the autonomous area.

S4—Complete recovery.

Pain can interfere with all these functional tests, because it can interfere with any normal activity of the patient. Its objective assessment is difficult.

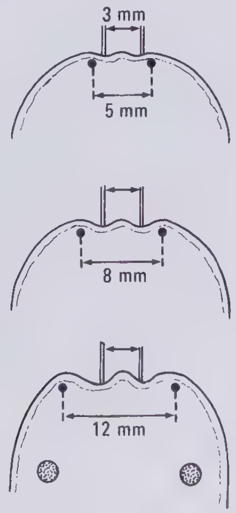


Figure 4–65. Increased pressure on the skin applied by the examiner in testing two point discrimination depresses a larger area of skin and the test will become unreliable. With light pressure, the two point discrimination will be 5 mm., but if the pressure is increased, a 3 mm. distance will be appreciated as if it were a 12 mm. distance.

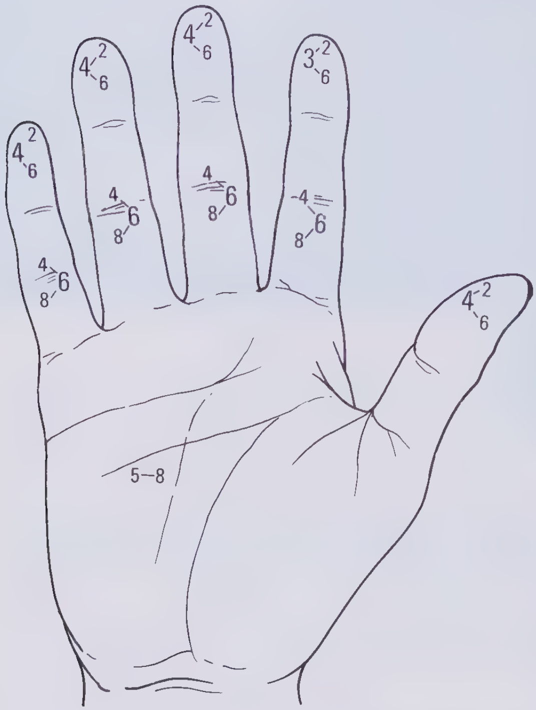


Figure 4–66. Values of discrimination in the Weber test in millimeters in the different zones of the palm. The largest figure indicates the average values and the two others, the minimal and maximal values. (After Moberg, 1958.)

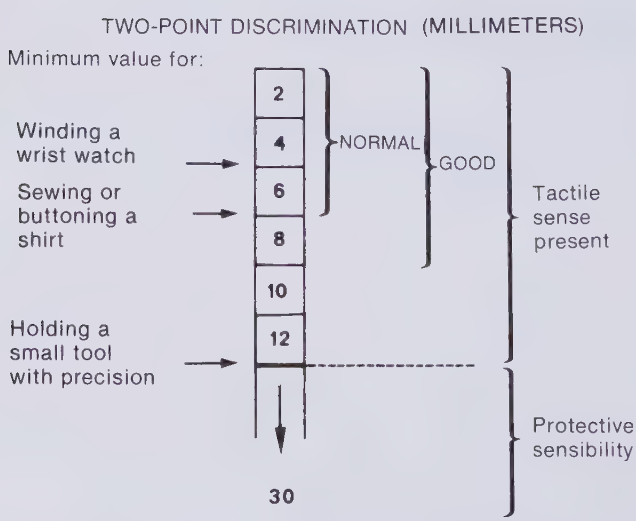


Figure 4–67. Recovery of the capacity for discrimination.

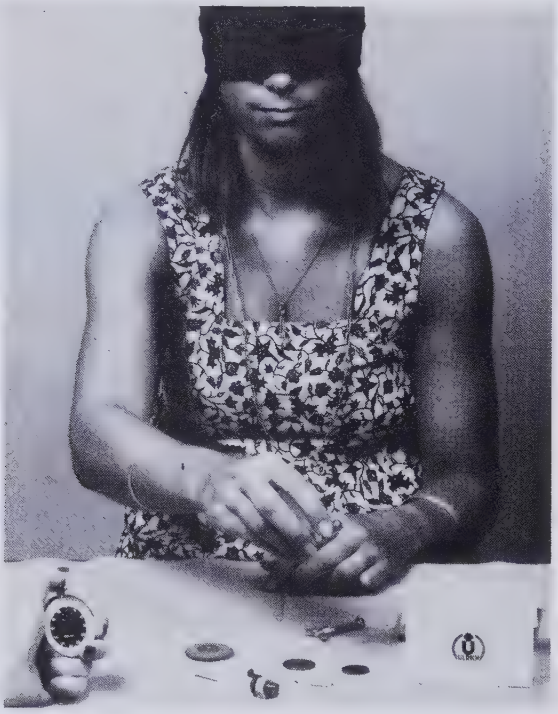


Figure 4–68. The Moberg "pick-up" test (see also p. 180).

ASSESSING SYMPATHETIC FUNCTION

It is customary to group arbitrarily under the heading "sympathetic" the various trophic disorders that follow peripheral nerve lesions. Lesions of the sympathetic fibers have a direct action on sweating and circulation. Other so-called "trophic disorders" depend on both sensory and sympathetic fibers.

After sectioning of a peripheral nerve, one often sees changes in the texture of the skin, which becomes dry, loses its elasticity, and develops a thinner epithelium. The nails become striated and brittle; their growth is slowed. The hairs may be longer and bushier, and elsewhere they atrophy and disappear, especially in patients with causalgia. In such patients the skin is often cyanosed, an indication of reduced blood flow. As a rule, the temperature of the skin is lower in the paralyzed zone, and even after reinnervation the part remains sensitive to cold. The consistency of the subcutaneous tissues also changes: The fat pads of the pulps and palm atrophy; this is most evident in the index finger after median nerve palsy. Atrophy of the skin, changes in blood flow, loss of sensation, and impairment of protective reflexes all increase the risk of injury and predispose to ulceration. These appear readily as a result of repeated minor trauma, pressure, or burns. Healing is slow to occur. The exposed anesthetic zones must be protected by wearing gloves, and the patient should be warned against injuries, which may lead to mutilation.

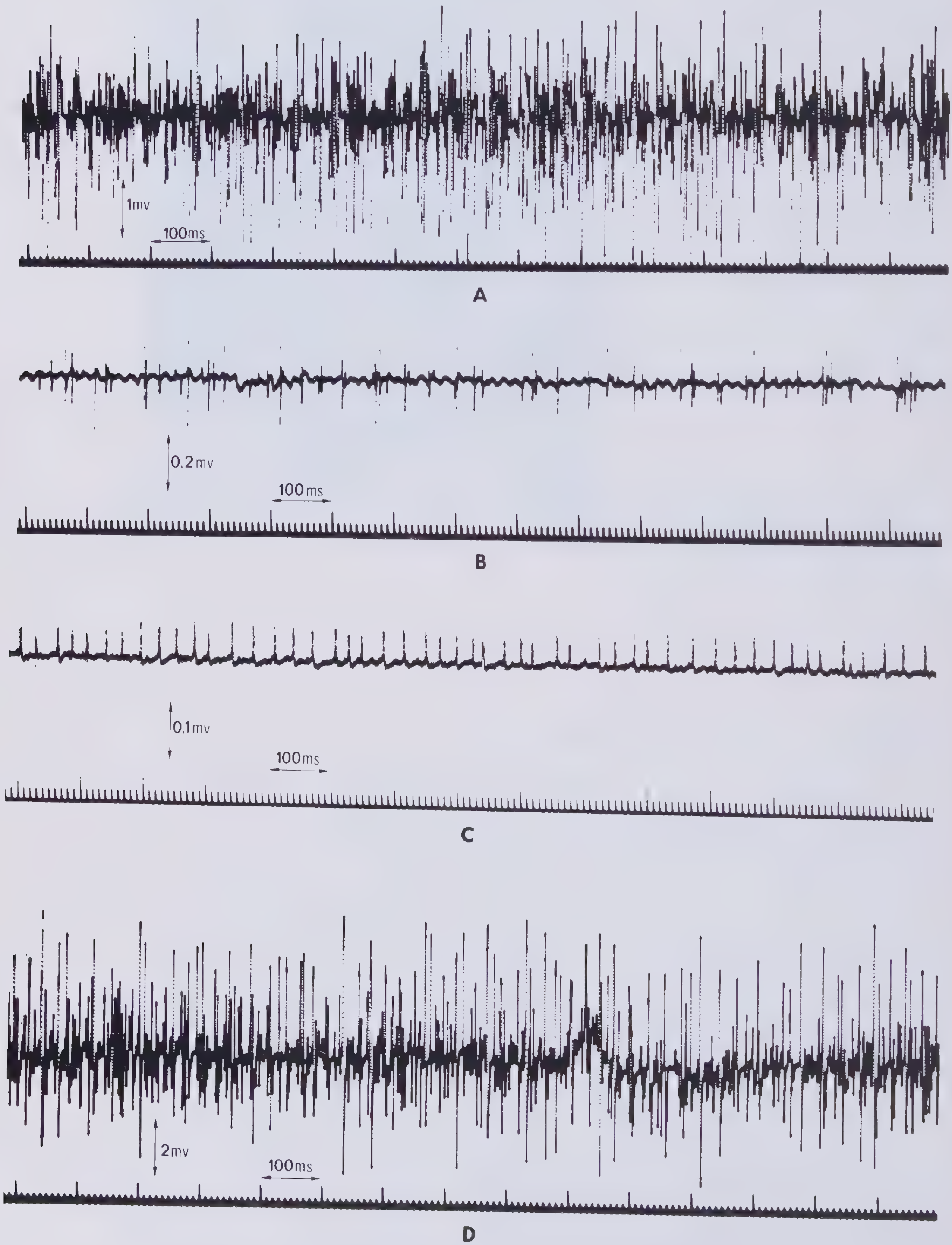


Figure 4–69. Electromyograms. *A*, Normal. *B*, Total denervation. *C*, Beginning of reinnervation by growth of axons. *D*, Return of muscle potentials three months after onset of paralysis, indicating regeneration.

ELECTRICAL TESTS IN LESIONS OF THE PERIPHERAL NERVES

Electrodiagnostic tests are particularly useful for the detection, localization, and prognosis of lesions of the peripheral nerves. They include electromyography, nerve conduction speed measurements distal to the lesion, and the study of action potentials. We shall mention here only the basic principles.

DIAGNOSTIC ELECTROMYOGRAPHY

This test confirms denervation of a muscle by demonstrating spontaneous activity at rest, which is always pathological, and temporal summation of motor unit potentials during voluntary contraction (high frequency potentials).

STIMULODIAGNOSTIC ELECTROMYOGRAPHY

This technique tests conduction in the motor and sensory nerve fibers (Fig. 4–69).

Motor Fibers: Stimulation of a Nerve Trunk at a Superficial Point in Its Course. One records within a muscle supplied by the stimulated nerve. From a determination of the latent period between the stimulus and the response, it is possible to measure the conduction velocity along motor fibers at different levels of the nerve (48 meters per second or more in the upper limb; 40 meters per second or more in the lower limb).

Sensory Fibers: Stimulation of the Sensory Fibers of a Given Nerve (e.g., Digital Collateral). One measures the response at a proximal point of the nerve. As with the motor nerves, this permits measurement of the conduction velocity at different points of the nerve.

Early electrodiagnosis is of limited interest. The process of wallerian degeneration can be recorded only four to five weeks after nerve division. Apart from helping in the detection of denervation, these tests can record spontaneous changes or changes after a nerve repair. However, it is always necessary to compare the clinical and electromyographic data.

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CHAPTER FIVE

SENSIBILITY EVALUATION

Although sensibility evaluation of the hands has been studied for centuries, it is still by no means completely understood. Much of the literature and widely practiced techniques of sensibility evaluation remain in need of further scientific investigation.

Moberg (1960) has long emphasized that the important factor in sensory function is one of quality and not merely the presence or absence of sensibility. He observes, "Why should the mere perception of touch or pain by the hand be accepted as a sign of normal sensation, when the perception of light is never identified with the normal capacity to see?" We must therefore question whether hand sensibility as it pertains to function can be discussed merely on the basis of known modalities for touch, pain, cold, and warmth. Testing the skin with a safety pin for pain, with cotton wool for touch, and with test tube contact for warmth or cold is inadequate for estimating functional loss. It is impossible to duplicate these tests periodically and obtain comparable quantitative results (Omer and Spinner, 1975).

The development of microsurgical techniques has increased the interest in improving the validity of our clinical methods of sensibility evaluation. We need to know whether one type of surgical repair is better than another. Postoperative results must be compared with the preoperative status to indicate whether and how much improvement has been obtained. Moberg (1978) defined the problem by stating that only the pooled results from many centers can provide us with answers, but to be meaningful these data must result from measurements on an identical scale with identical devices.

Consistent with these principles, sensibility testing at the Hand Rehabilitation Center in Philadelphia, Pennsylvania, does not depend upon gross methods such as cotton wool, or pin pricks, or any single test. Rather we use several complementary quantitative tests repeated at regular intervals to answer three questions: Is protective sensation present? Is light touch present? And if light touch is present, what is the level of discriminative sensation (Callahan, 1983)? Our battery of tests for the assessment of sensibility may be divided into three groups—the modality test (Semmes-Weinstein monofilaments), functional tests (two point discrimination, localization, and the Moberg pick-up test), and nerve conduction studies (Callahan, 1983). We believe that this test battery most closely approximates the Moberg ideal of "quality" by broadening the range of hand function tested.

THE MODALITY TEST

The modality test evaluates the perception of the four modalities—warmth, cold, pain, and light touch–deep pressure. Von Frey first described the use of graded stimuli to evaluate cutaneous sensibility in the late 1800's. In an attempt to standardize the technique, he found that horsehairs of varying thicknesses bend at specific milligrams of axial loading pressure. By pressing on the skin with a thorn glued to the end of a hair until the hair started to bow, von Frey obtained a measure of the pressure sensibility of nerve fibers in the skin. He calibrated the hairs on a balance, varying stiffness by changing length and by using hairs of different densities. He recorded pressure sensibility by noting whether a given hair touched to the skin produced any sensation.

In 1960 Semmes and Weinstein and their colleagues made the testing procedure more exact when they reintroduced von Frey's method, using nylon monofilaments mounted in Lucite rods. The monofilaments, known as the Semmes-Weinstein pressure aesthesiometer,* are calibrated to exert specific pressures. Twenty graduated filaments, differing in pressure, are included in the testing kit (Fig. 5–1). The filaments are marked with numbers ranging from 1.65 to 6.65. The filament number represents the logarithm of 10 multiplied by the force in milligrams required to bow the filament. Except for the very largest, all filaments buckle as the examiner presses them against the skin (Fig. 5–2). As long as first-order buckling is maintained, the pressure exerted on the skin varies only with the length and diameter of the calibrated filament, not with the force applied by different examiners. First-order buckling is the bowing produced in a properly applied Semmes-Weinstein filament, in which the lower end of the mounted filament is "pinned." This position is achieved when the examiner applies only those lateral forces necessary to keep the top end directly over the lower end when the filament is in contact with the skin (Levin et al., 1978).

In 1967 von Prince and Butler used the Semmes-Weinstein monofilaments clinically to test light touch–deep pressure in patients with nerve injuries from war wounds. They required perception of touch by a given filament and localization of the area of touch for an accurate response. They correlated two point discrimination and perception of light touch as measured by the monofilaments to develop an interpretive scale that divides the patient's performance into graduated levels of sensibility. These levels are designated as normal, diminished light touch, diminished protective sensation, and loss of protective sensation.

FUNCTIONAL TESTS

TWO POINT DISCRIMINATION

Light touch two point discrimination establishes the presence of functional sensation or the fine sensibility required to manipulate small objects. Testing of two point discrimination was introduced by Weber in 1835. It involves touching the skin with one or two blunt points of an eye caliper or Boley gauge (Fig. 5–3). Both instruments are calibrated in millimeters. The points of an eye caliper must be ground flat to eliminate sharpness. The distance between the points is varied, and the patient is required to recognize whether he has been

*Research Designs, Inc., Suite 103, 7320 Ashcroft Street, Houston, Texas 77081.

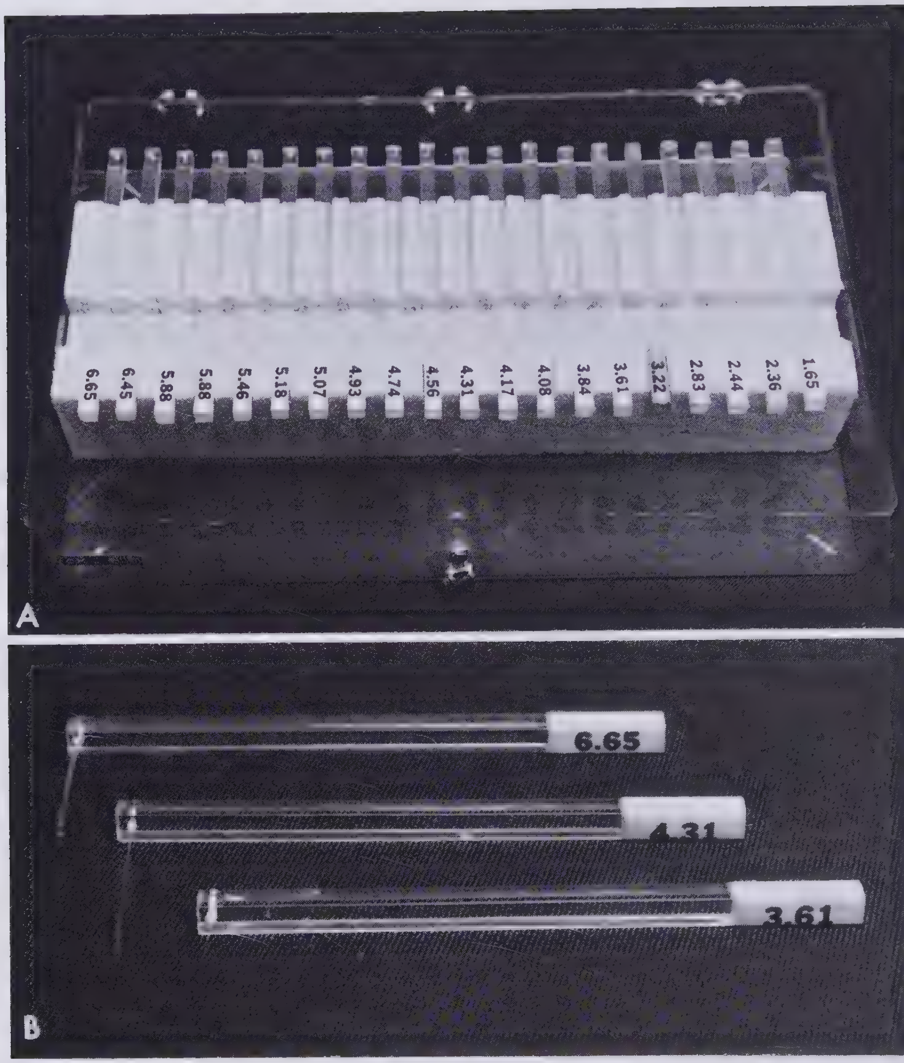


Figure 5–1. *A,* Twenty calibrated filaments, varying in pressure, are included in the testing kit. *B,* Close-up view of filaments.

touched with one or two points. The points are applied along a longitudinal axis of the extremity in the center of the finger tip. Investigators have differed in regard to the proper threshold value for this test. McDougall (1903) placed it at eight correct answers out of 10 for two point stimuli. Pontin (1960), Mannerfelt (1962), and Moberg (1962) each required seven. Pontin also required that the patient give at least seven correct answers out of 10 for one point stimuli (Onne, 1962). The American Society for Surgery of the Hand recommends seven correct answers out of 10 for two point discrimination. The value of this test has been variously assessed. Moberg (1960, 1962) stated that there is no better test for evaluating tactile gnosis, although he conceded that the test is not ideal because it requires the patient's cooperation.

Werner and Omer (1970) found in the administration of 4000 tests in 787 patients that the presence of light touch does not necessarily indicate that light touch two point discrimination is present. Therefore, light touch two point discrimination is an essential part of the sensibility evaluation for demonstrating the presence of functional sensation.

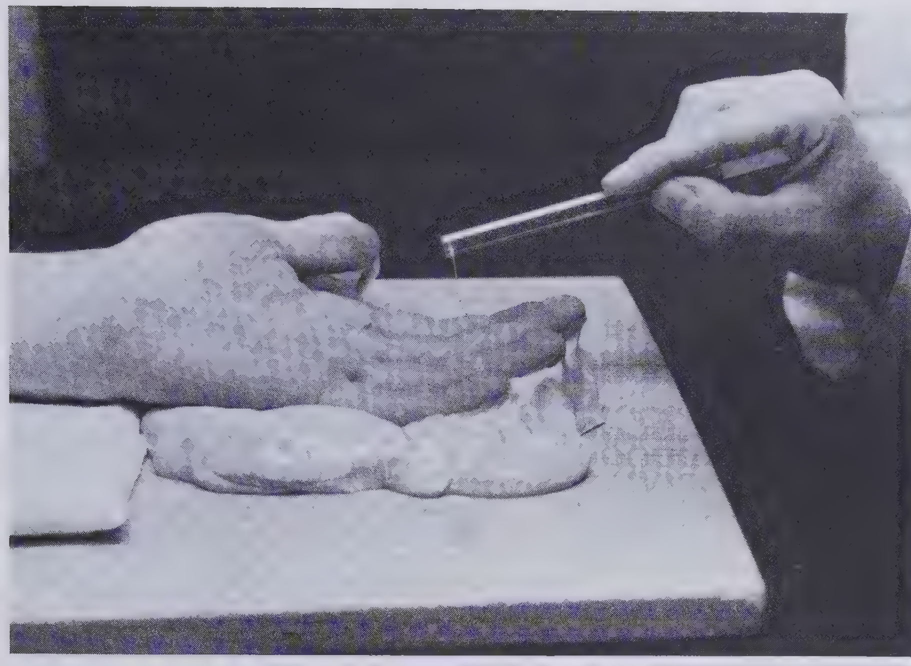


Figure 5–2. First order buckling. The monofilament is applied perpendicular to the hand or digit surface. Pressure is increased until the monofilament bends. The patient's hand is supported in putty because motion misleadingly improves test results.

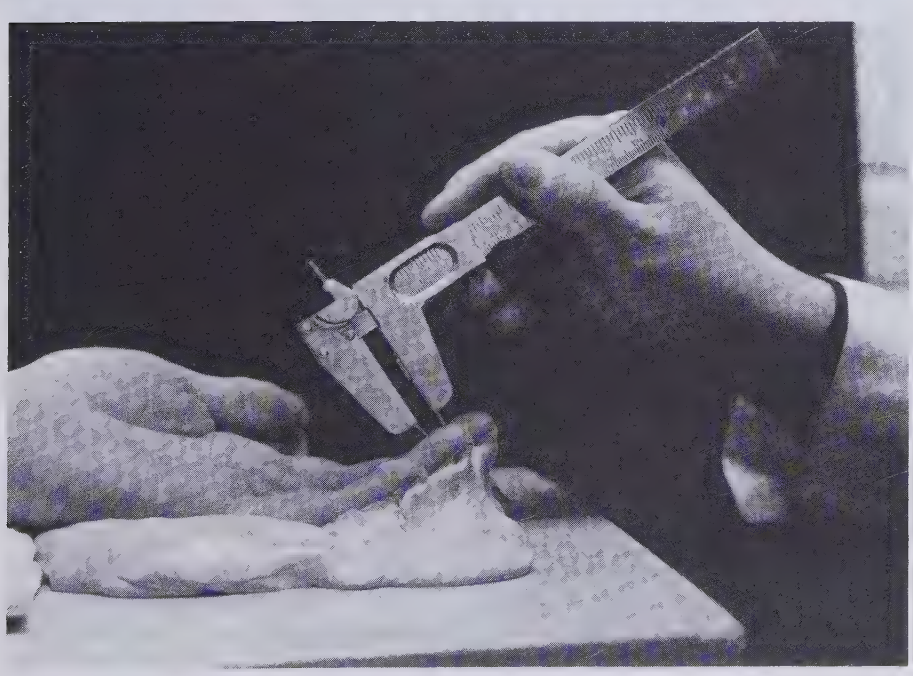


Figure 5–3. Light touch two point discrimination test to determine whether the patient can discriminate between being touched with one or two points and the minimal distance at which the two points are recognized. The testing instrument is a Boley gauge.

LOCALIZATION

Localization has been tested by various investigators using different instruments. Werner and Omer (1970) used the Semmes-Weinstein monofilaments to classify the patient's response according to point localization instead of area localization, as in the von Prince study. Area localization is the ability to recognize the stimulus but not at the exact point, whereas point localization is the identification of the exact point. The patient closes his eyes while the examiner touches the skin with a given filament. If the patient perceives the stimulation, he opens his eyes and identifies the touch point. A ⅜ inch diameter wooden dowel is used to localize the stimulus. A correct response is one in which the point stimulated must be covered by the wooden dowel or be in contact with a point on the circumference of the dowel. Correct or incorrect responses are recorded in the appropriate area on a worksheet. Werner and Omer recommend that point localization be required in sensibility evaluation of the hand because it reveals more precise sensibility (Omer and Spinner, 1975; Werner and Omer, 1970). Slowness of response and unsure localization are signs of depressed sensibility.

MOBERG PICK-UP TEST

The Moberg pick-up test is a test of function (Fig. 5–4). A box of approximately nine small everyday objects is placed on the table in front of the patient. The objects might include such items as a nut and a bolt, a paper clip, coins, a safety pin, and a screw. The patient is asked to pick up the objects one at a time from the table top and put them into a box, first with his injured hand and then with the uninvolved hand. He does this first with eyes open and then with eyes closed. The examiner times the patient with a stopwatch and observes the manner of prehension (see also p. 191).

TEST BATTERY

Sensation is the perception through the senses, or the subjective appreciation of a physical stimulus. Sensibility is the capacity for sensation, that is, the ability to perceive a physical stimulus.

Sensibility testing begins by gathering background information, including an accurate history of the injury, a subjective description of his symptoms by the patient, assessment of trophic changes, joint range-of-motion measurements, muscle evaluation, and quantitative tests of motor function, including grasp and pinch. After this information has been gathered, the sensibility tests are administered. A detailed evaluation is mandatory if accurate data are to be available for comparison studies. Without such careful evaluation it is impossible to determine whether a patient's recovery following a nerve injury is progressing on schedule or is slower than anticipated.

Testing should be done in a sound-resistant or quiet room with only the therapist and patient present. A quiet, distraction-free environment is of the utmost importance, since nothing (a child crying, people talking, typing) should interfere with the patient's or examiner's concentration. The room temperature should be comfortable and free of excess humidity.

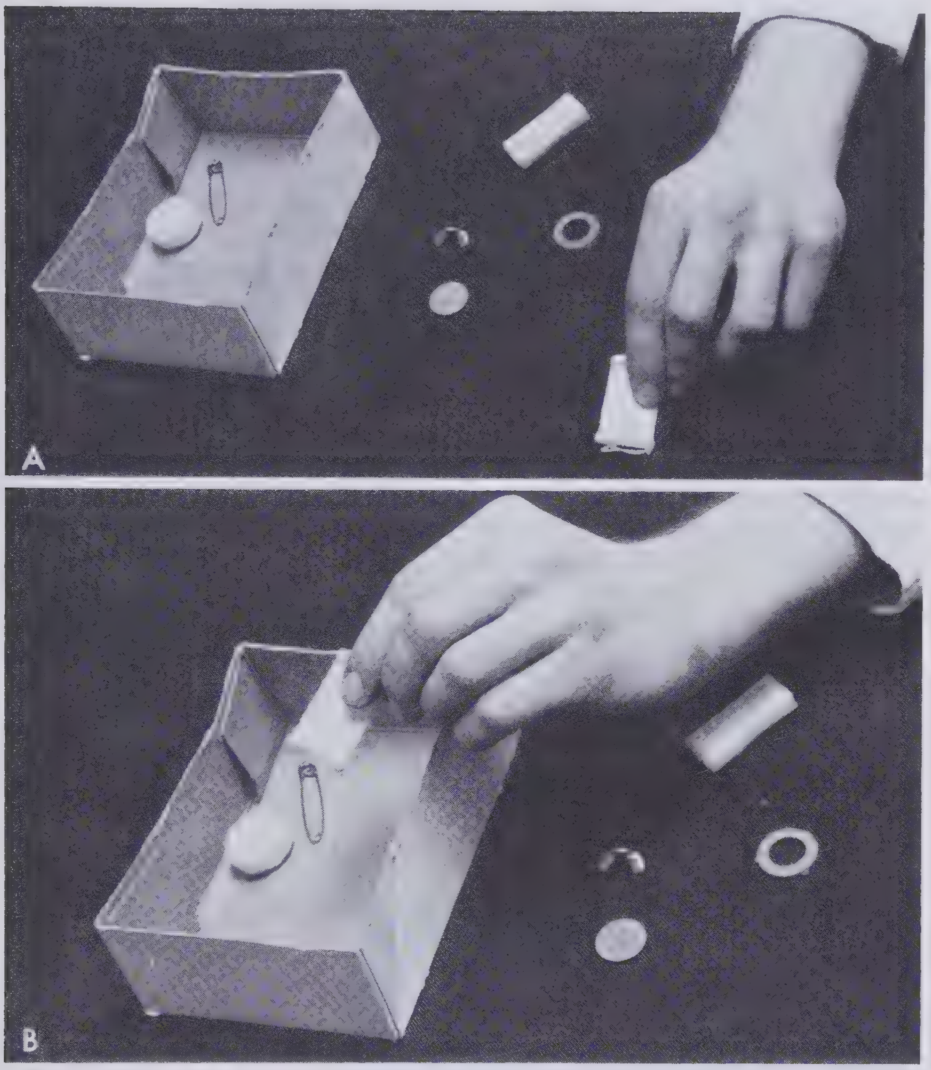


Figure 5–4. *A,* The Moberg pick-up test. *B,* The test assesses the patient's functional aptitude in picking up objects one at a time and placing them in a container, first with the eyes open and then with the eyes closed.

BACKGROUND INFORMATION

History. One records the age, sex, occupation, hand dominance, date of the injury, location of the injury, mechanism of injury, diagnosis, date and type of surgical procedure, and other pertinent information. The date of the injury and the type of surgical procedure are essential data because each defines a predictable time course for recovery. Each characteristically influences recommendations for treatment, sensibility re-education, and return to work. Notation of the mechanism of injury aids the examiner in understanding differences in individual recovery. If, for example, the patient sustained a severe crushing injury with massive tissue damage, scarring and pain may affect grip strength and loss of muscle power. In contrast, nerve lacerations with little other tissue damage present a better prognosis (Wilgus, 1982).

Subjective Description of Symptoms by the Patient. One should include the patient's description of his symptoms and ability to use his hand (numbness, pins and needles, tingling, pain, burning, improvement noted with rest, and ability to use it in activities of daily living). The activities and hand positions that make his condition worse should also be recorded. Not all patients are good historians. A patient who states that his hand "feels fine" may show a measurable loss of sensibility. Another patient who states that he "feels nothing" in the median nerve distribution may be amazed at how much he does "feel" after the surgeon uses a local anesthetic to block the ulnar nerve.

Assessment of Trophic Changes. One includes observation of atrophy and nail changes. Burns, blisters, cuts, or bruises on the fingers are indicative of the insensitive hand. The skin condition must be noted (dry, scaly, moist, mottled, pale, shiny). The presence of edema or infection may affect the true validity of the evaluation. Does the patient complain of cold intolerance? Sweating in an area supplied by a peripheral nerve is indicative of peripheral nerve regeneration, and the absence of sweating indicates a peripheral nerve lesion. A patient with a laceration in the peripheral nerve area will not sweat, and therefore his skin will have a very dry appearance. Although sweating is an indication of pseudomotor activity in the finger, there is no relationship between the return of sweat production and the quality of sensibility recovery. The Ninhydrin sweat test developed by Aschan and Moberg (1962, 1958) has been used as an objective test in uncooperative patients to obtain information about the function of a nerve.

Joint Range-of-Motion. Active and passive range-of-motion measurements are evaluated with a goniometer (Fig. 5–5).

Muscle Evaluation. A voluntary muscle test will establish the level of

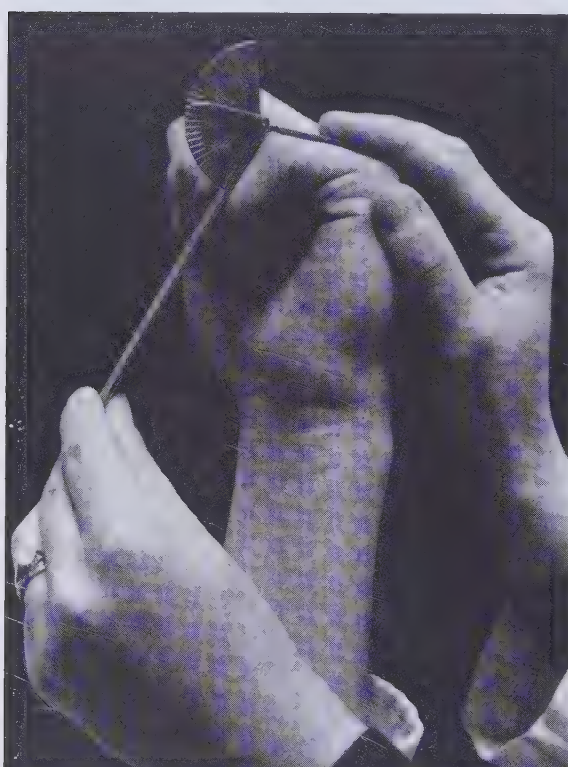


Figure 5–5. Active and passive ranges of motion are measured with a goniometer.

function and provide an estimate of the strength of the active muscles. Manual grading of weak muscles and the identification of normal muscles must be accurately recorded. Trick movements must be detected. If there is questionable motor activity, a local anesthetic may be indicated to block competing innervation. Muscle bulk in the involved forearm is measured and compared with that of the uninvolved extremity. The examiner should describe the patient's coordination and the presence of pain as related to muscle function.

Grasp and Prehension. Prehension and grasp measurements are checked and compared with those of the uninvolved extremity. The grip of the nondominant hand is generally slightly less than that of the dominant hand. Grip strength is measured on the adjustable Jamar dynamometer (Fig. 5–6). The combined efforts of the intrinsic and extrinsic muscles are evaluated on levels 1, 2, and 3. Primarily extrinsic muscle function is evaluated on levels 4 and 5. The patient's cooperation will be demonstrated during the Jamar dynamometer test. Normal adult grip measurments for the five consecutive handle positions create a bell curve. The first position is the least favorable for strong grip, followed by the fourth and fifth positions. The strongest grip measurement occurs at the second and third handles.

Pinch can be quantitated on the pinch meter. Pulp as well as key pinch should be evaluated and recorded (Fig. 5–7).

Proprioception. With normal sensation the patient with vision blocked can identify the positional and directional change in a finger when performing passive movements of the interphalangeal joints (Omer, 1981). To test proprioception, the examiner supports the patient's finger laterally and moves it 0.5 to 1.0 cm. in any direction. The patient must identify the angle through which the joint is moved.

Figure 5–6. Grip strength is measured on the five levels of the adjustable Jamar dynamometer.

Figure 5–7. Finger pinch is measured on the pinch meter. *A,* Pulp pinch. *B,* Key pinch.

THE MODALITY TEST (SEMMES-WEINSTEIN MONOFILAMENTS)

When testing is begun, the area of sensory dysfunction is mapped out. The examiner draws a probe lightly across the patient's hand, beginning with an area of normal sensibility and progressing slowly to an area of suspected abnormal sensibility. A pen or any instrument that is not sharp or too wide may be used. The patient with his vision blocked is asked to indicate immediately when and whether he perceives a change in feeling. The examiner marks the skin with a felt tip pen where the sensory change occurs. The process is repeated until the proximal, distal, and lateral borders of sensory dysfunction have been determined (Fig. 5–8). The examiner then tests for light touch within

Figure 5–8. The examiner draws a probe across the skin to determine the proximal distal and lateral borders of sensory dysfunction. Vision is blocked by having the patient close his eyes or by the use of a wooden screen.

this area. Mapping makes the testing quicker and more effective, because follow-up evaluations require only that the area of dysfunction in the initial examination be re-evaluated. The process may be repeated during successive evaluations. It gives the patient and the examiner the opportunity to note whether the area mapped out diminishes in size or remains the same over a period of time. An alternate method is to have the patient himself outline the area of dysfunction in his hand. The results of the mapping can be recorded on an outline of a hand for serial comparison (Callahan, 1983).

Documentation is assessed by the use of a worksheet that has a grid superimposed on an outline of the hand (Fig. 5–9). The grid, devised by von Prince and Butler (1967), is divided into squares or zones. Transverse lines correspond to the flexion creases of the digits and palm. Longitudinal lines are parallel with the rays of the hand. The examiner visualizes the grid on the patient's hand, applies the filament to a given zone in random sequence, and asks the patient to respond. Correct or incorrect responses can be recorded in the appropriate area on the worksheet (Callahan, 1983).

The patient's hand must be fully supported by the therapist's hand or braced on the table. At the Hand Center we prefer to support the hand in putty (Brand, 1980; Fig. 5–2). Vision is blocked by asking the patient to close his eyes or by the use of a wooden screen (Fig. 5–8). The patient must also be in a position that does not cause discomfort in the arm.

Clinical testing techniques using the Semmes-Weinstein monofilaments have been developed by von Prince and Butler (1967), Werner and Omer (1978, 1981), and Bell (1978, 1983). Testing should begin with the uninvolved extremity. This allows the patient to become familiar with the testing procedure, and the examiner can establish the patient's normal level of sensibility. Higher values may be considered normal when the measurements of the uninvolved extremity are higher than established normal values.

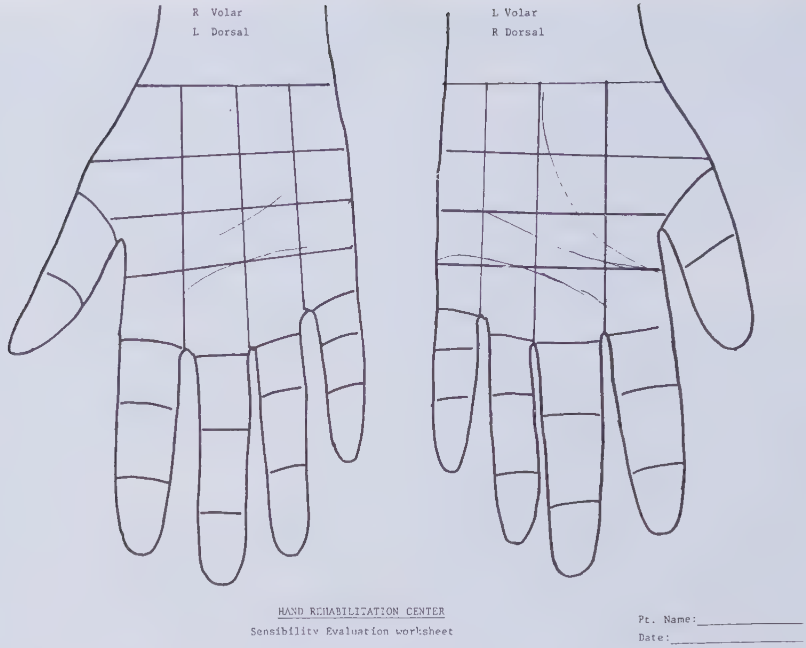


Figure 5–9. Documentation is more accurate with the use of a worksheet that has a grid superimposed on an outline of the hand. The grid is divided into seven palmar zones. The transverse lines correspond to the flexion creases, and the longitudial lines correspond to the rays of the hand.

The initial test following a nerve laceration or crush includes both surfaces of the involved hand, with special emphasis on the area of dysfunction as determined by mapping. The examiner visualizes the "grid" on the patient's hand and applies the monofilament at the center of any given zone (Fig. 5–10). Should a more detailed evaluation be needed (e.g., following digital nerve repair), the zones can be subdivided. Some examiners may prefer to mark the responses with a felt pen directly on the patient's hand for easier reference.

The monofilament is applied perpendicular to the skin until the monofilament bends (Fig. 5–2). Testing is begun with filament 2.83, which tests for normal light touch sensibility. With patients who have severe dysfunction, the examiner may choose to begin testing with a higher numbered filament. Skin that is callused will have a higher sensory threshold than uncallused skin. These areas should be noted and considered in the interpretation of the results.

When monofilaments 1.65 through 4.08 are used, the filament is applied three times in a chosen zone. The filament is applied to the skin for 1 to 1.5 seconds, held in place for 1 to 1.5 seconds, lifted for 1 to 1.5 seconds, and then applied two more times in the same manner. The filament must not slip on the skin when it is being applied, for this will give an additional stimulus clue to the patient. When filaments 4.17 through 6.65 are used, only one stimulation is applied in a chosen zone. With the patient's hand supported in putty and his vision blocked, the examiner touches the skin with a filament. As soon as the patient perceives the pressure of the stimulus, he responds by saying the word "touch." He must respond accurately to the specific filament on two nonsuccessive trials before testing in a zone is considered complete. If the first response is accurate and the second inaccurate, a third trial is used to make a final assessment of that zone. When the responses are inaccurate for two trials with a given filament in a particular zone, the examiner returns to that zone at varying intervals with thicker filaments until a correct response is elicited. If a

response is not obtained with the thickest filament marked 6.65 in a particular zone, a pin-prick test is used as a final test of sensibility in that zone.

Callahan (1983) emphasizes the importance of accurate recording of responses, because it is easy to forget where the stimulus has been applied previously and how the patient responded. Careful recording makes the test shorter, more accurate, and more valid in serial comparison tests. It also documents inconsistencies in the responses of a suspected malingerer. She suggests a code for the worksheet as follows: +2.83 (first positive response to 2.83 monofilament), + +2.83 (second positive response; testing complete in that zone), −2.83 (first negative response to 2.83), − −2.83 (second negative

Figure 5–10. The examiner visualizes the "grid" on the patient's hand and applies a monofilament to the center of any given zone. *B,* The response is recorded on a grid superimposed on an outline of the hand.

Table 5–1. LIGHT TOUCH–DEEP PRESSURE: SCALE OF INTERPRETATION

Code		Filament
Green	Normal light touch	2.36–2.83
Blue	Diminished light touch	3.22–3.61
Purple	Diminished protective sensation	3.84–4.31
Red	Loss of protective sensation	4.56–6.65
Red lined	Unresponsive to 6.65	

response to 2.83; test at random intervals with thicker filaments until accurate responses are obtained), +3.22 (first positive response to 3.22), and so on. Detailed documentation of this nature requires a worksheet with a life sized outline of the hand to provide space for notations. The examiner may prefer to devise his own code.

The scale of interpretation shown in Table 5–1 enables the examiner to make a meaningful interpretation of the sensibility test results. The norms in the scale, although not standardized, are based on clinical testing of hundreds of nerve-injured hands (Werner and Omer, 1970). The numerical values of the filaments recorded on the worksheet are transferred to a color coded outline of a hand for easy reference and serial comparison (Bell, 1978, 1983; Fig. 5–11). The colors correspond to the sensibility levels in the scale of interpretation. For example, the color green indicates normal light touch (2.83) perceived, blue indicates diminished light touch (3.22–3.61) perceived, purple indicates diminished protective sensation (3.84–4.31) perceived, and red (4.56–6.65)

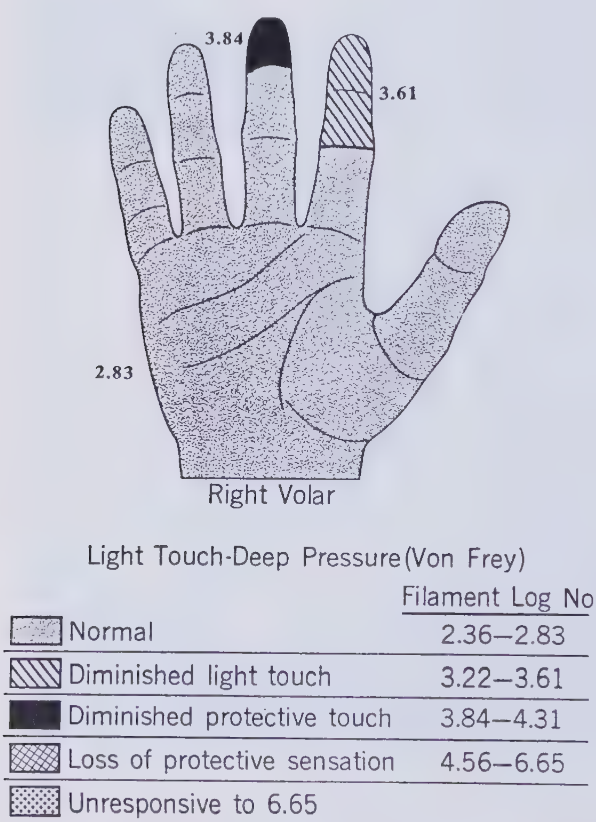


Figure 5–11. A coded outline of the hand is an easy reference for serial comparison.

indicates loss of protective sensation. A red lined area indicates that no filament was perceived.

According to a study conducted by Levin et al. (1978), an advantage of the Semmes-Weinstein filaments in measuring threshold sensitivity is their ease of application. However, correct interpretation of the results requires an understanding of the factors that can affect those results. According to their engineering analysis, the principal factors that can lead to variations in the stress required to buckle or bend a filament are the method of application by the examiner, variations in the elastic modulus due to elevated temperatures or high humidity, differences on the ends of the filaments, and variations in the attachment of the filaments to the handles. Extreme humidity affects the stiffness of the lighter Semmes-Weinstein monofilaments and therefore changes the pressure that they exert on the skin. The filaments should be stored where they will not be affected by humidity. With continued use or mistreatment, the filaments become bent. These should not be used until they are straightened. Time seems to correct the bend (Werner and Omer, 1970). Filaments that cannot be manually realigned should be replaced.

FUNCTIONAL TESTS

Two Point Discrimination

The Weber two point discrimination test is used to further quantify the level of sensibility (Bell, 1983). The test determines the minimal distance at which a patient can discriminate between being touched with one or two points. Moberg (1958) prefers to use an ordinary paper clip with a wire diameter of about 0.9 mm. as the testing instrument. Paper clips are not used by many examiners because the manufacturing process results in a sharp barb on one end of the clip, which stimulates pain receptors. A Boley gauge* (or other caliper with blunt ends) is recommended (Fig. 5–3). In addition the Boley gauge measures the exact distance between the points in millimeters and can be adjusted in 1 mm. increments.

The test procedure should be explained and demonstrated first while the patient observes. His hand should be fully supported. During testing, the patient's vision is blocked with the use of a screen (Callahan, 1983), or the patient is asked either to close his eyes or look in another direction when the stimulus is applied. The gauge is set at a 5 mm. distance between the two points. One point is touched or two points are touched in random sequence along a longitudinal axis in the center of the finger tip. In applying two points, both points should contact the skin simultaneously. The instrument is applied lightly to the point of blanching of the skin (Omer and Spinner, 1975). The patient must respond each time he feels the stimulus. If he cannot recognize that he has been touched with one or two points, he should respond by saying "I do not know." Ten separate stimuli are given. Seven out of 10 responses must be correctly identified. If the patient cannot distinguish seven out of the 10 stimulations correctly, the distance between the two points is increased and the stimulation is repeated until the patient gives the required accurate responses. Testing is stopped at 15 mm. if the response is nondiscriminatory.

The interpretation of scores is based on the American Society for Surgery of the Hand Clinical Assessment Recommendations:

*Research Designs, Inc., Suite 103, 7320 Ashcroft Street, Houston, Texas 77081.

1. Normal—less than 6 mm.
2. Fair—6 to 10 mm.
3. Poor—11 to 15 mm.
4. Protective—one point perceived
5. Anesthetic—no point perceived

Moberg states that 6 mm. of two point discrimination is necessary on both sides of the pinch to wind a watch or to put a 5 mm. nut on a screw; 6 to 8 mm. for sewing with an ordinary needle or buttoning a small button; and 12 to 15 mm. for handling small precision tools. Above 15 mm. two point discrimination, gross tool handling may be possible but only with decreased speed and skill. The test values are recorded on a serial test form.

Point Localization

Point localization using the Semmes-Weinstein monofilaments is treated as a separate functional test at our Hand Rehabilitation Center. It is considered to reflect a higher level of integration than light touch stimulation.

With the patient's hand fully supported on putty and his vision blocked, the examiner applies a filament to the center of a particular zone. The examiner begins with the lowest numbered filament that resulted in a positive response during light touch testing. As soon as the patient perceives the stimulus, he opens his eyes and localizes the touch point by pointing to it (Fig. 5–12). The filament is applied only once to each zone. The speed of the response is related to the level of sensibility. If the patient correctly localizes the stimulus, a dot is marked in the corresponding zone on a worksheet. A worksheet with the grid superimposed on the outline of a hand is again more useful for documentation of the testing results. If the stimulus is incorrectly localized, an arrow is drawn on the worksheet from the point of the stimulation to the point, area, or finger where the touch is referred (Fig. 5–13). This mapping of the patient's

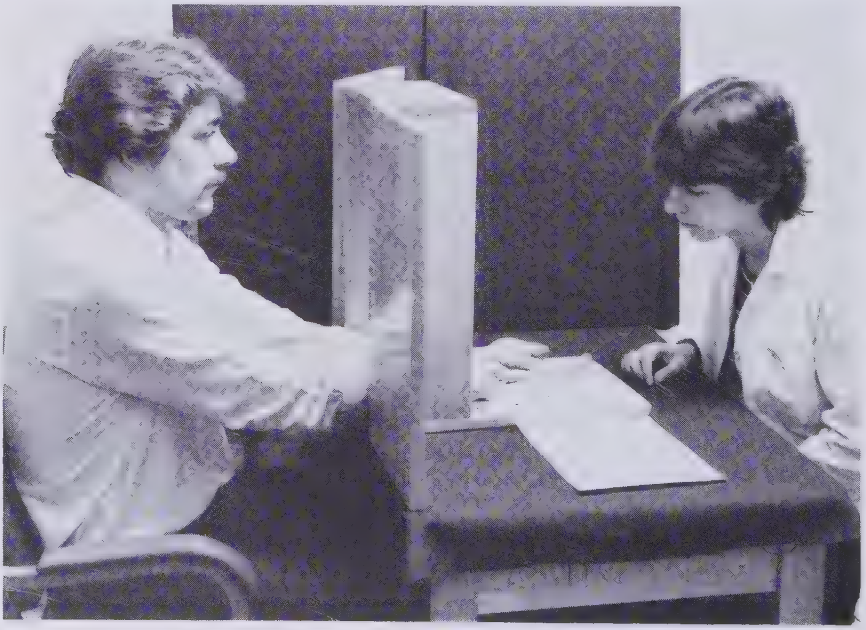


Figure 5–12. The patient localizes the touch point by pointing to it.

responses gives the patient and the examiner a picture of the patient's level of localization. Serial testing should show fewer and shorter arrows (Callahan, 1983).

Moberg Pick-up Test

Tactile gnosis is the fine sensibility of the finger pulps that permits recognition of what is being touched without the aid of sight. Moberg (1978) has stated that a hand without tactile gnosis is "blind" and is useless without the aid of vision. Every evaluation of sensibility in the hand should include a test of tactile gnosis.

The pick-up test introduced by Moberg (1958) assesses general sensibility and tactile gnosis. The advantage of the pick-up test is that it combines sensibility with motion requiring active manipulation and recognition of an object. The patient is required to pick up nine objects of different shapes and sizes, one at a time, as quickly as he can and place them in a container (Fig. 5–4). The objects can include such items as a safety pin, a paper clip, a screw, a key, a marble, coins, and a nut and bolt. The test is first done with the involved hand and then with the uninvolved hand. The patient is then asked to close his eyes and the test is repeated. The patient is timed with a stopwatch each time he performs the test. The rapidity and the manner of prehension are recorded, and a comparison is made between the involved and uninvolved hands. When picking up objects with his vision blocked, the patient will not use regions of poor sensibility. If sensibility in the median nerve is impaired, the patient will pick up the object with his thumb and ring and little fingers instead of normally using the thumb and index finger.

The test can be made more difficult by asking the patient to name or describe the objects as he picks them up with his eyes closed (Moberg, 1958). Omer (1981) suggests that on occasion a piece of chalk be used as an object so that the chalk residue remains to show the functional surfaces of the hand.

Periodic tests will indicate the changing status of coordination. Omer (1981) found that the normal time for picking up nine objects is less than 10

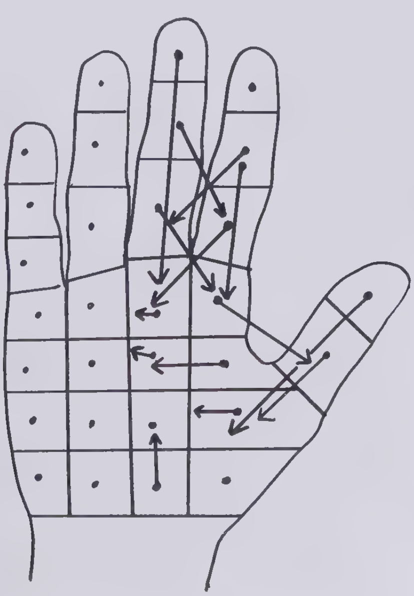


Figure 5–13. Arrows drawn from the point of stimulation to the point where the touch is referred give the examiner and the patient a picture of the patient's level of localization.

P.1

HAND REHABILITATION CENTER
901 Walnut Street
Philadelphia, Pa. 19107

SENSIBILITY EVALUATION SUMMARY

Name________________________ Eval. #______________

Chart #______________________ Date:______________

Dominance____________________ Ex: ______________

Age ____

HISTORY:

PATIENT SUBJECTIVE DESCRIPTION

L/R L/R

Sensation Decreased

Sensation Absent

Paraesthesia

ROM

SYMPATHETIC FUNCTION

MUSCLE FUNCTION

Grip (lbs.) (Jamar #_____)

R) 1________ L) 1________

2________ 2________

3________ 3________

4________ 4________

5________ 5________

Pinch (lbs.)

Lateral R)____ L)______

Pulp R)____ L)______

6/82

Figure 5–14. A detailed and careful documentation is required if accurate evaluation is to be available for comparison studies.

seconds. However, the importance of this test is that the examiner can observe the patient's functional aptitude for picking up the objects.

NERVE CONDUCTION STUDIES

Nerve conduction–velocity testing measures the speed at which impulses travel over the course of a peripheral nerve. It is an important tool to complete the clinical evaluation.

SENSIBILITY EVALUATION SUMMARY

P.2

Chart#: ________

Eval. #: ________

Date: ________

Tactile Gnosis (Moberg Pick-Up Test: ______ objects)

	R	L
Eyes Open	sec.	sec.
Eyes Closed	sec.	sec.

Comments:

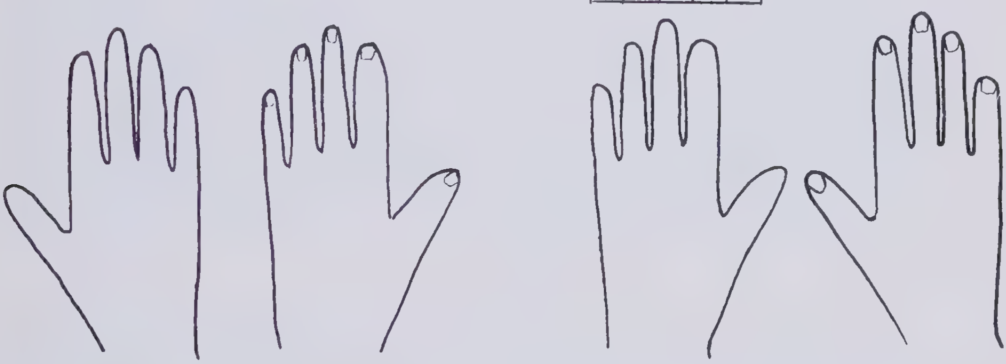
TWO POINT DISCRIMINATION (mm.)

LIGHT TOUCH - DEEP PRESSURE (VON FREY)

Two Point Discrimination (mm.)	I	II	III	IV	V
R				/	
L				/	

2PD:

2PD:



(L) VOLAR (L) DORSAL (R) VOLAR (R) DORSAL

ASSH 2 P.D. SCALE

0mm - 6mm	Normal
6mm - 10mm	Fair
11mm - 15mm	Poor
1 Point Perceived:	Protective
No Point Perceived:	Anesthetic

LIGHT TOUCH - DEEP PRESSURE: SCALE OF INTERPRETATION

Green	Normal	2.36 - 2.83
Blue	Diminished light touch	3.22 - 3.61
Purple	Diminished protective sensation	3.84 - 4.31
Red	Loss of protective sensation	4.56 - 6.65
Red Lined	Unresponsive to 6.65	

6/82

Figure 5–14. *Continued*

SUMMARY

No single method of sensibility evaluation may be appropriate for every patient or the choice of every examiner. Different clinicians use different tests. However, the complexity of sensibility is such that no single test or category of tests in clinical use today can provide the full picture of sensibility. Therefore the most complete picture will result from a carefully chosen battery of tests selected to answer three questions: Is protective sensation present? Is light touch present? And if light touch is present, what is the level of discriminative

sensation? With this in mind, the battery of tests used at the Hand Rehabilitation Center in Philadelphia, Pennsylvania, includes the Semmes-Weinstein pressure aesthesiometer, two point discrimination, localization, the Moberg pick-up test, and nerve conduction studies. We have found that this battery of tests provides the desired information in the majority of patients referred for sensibility evaluation.

Isolated tests of nerve loss and recovery are of little value. Postoperative results must be compared with the preoperative status to indicate whether and how much improvement has been obtained. An appropriate battery of tests should be repeated at intervals of approximately 12 weeks to chart the changing status of the injured nerve (Fig. 5–14). Since they are quantitative tests, they have meaning for other examiners and the patient.

Cutaneous sensibility has been studied since the time of Aristotle (350 B.C.). Von Frey's classic study in 1895 merits him special praise. In the process of learning, new techniques and new ideas have emerged through the clinical studies of Moberg, von Prince, Werner, Omer, and Bell. Much is yet to be learned, as indicated by the differing opinions and testing techniques. Critical scientific investigations by these examiners and others have provided us with the basis from which to draw upon and further develop our methods of assessing the quality of sensibility remaining in the hand following a nerve injury.

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CHAPTER SIX

PARALYSIS OF THE PERIPHERAL NERVES

We shall consider briefly the course, relations, and distribution of the main nerves of the upper limb and the clinical features of nerve paralyses of the upper limb.

AXILLARY NERVE PALSY

The axillary or circumflex nerve (C5, C6) is the lateral terminal branch of the posterior cord (Fig. 6–1). It runs alongside the posterior circumflex artery at the lower border of subscapularis. Together they form a neurovascular pedicle, which winds around the surgical neck of the humerus from medial to lateral and from posterior to anterior under cover of the deltoid muscle.

The funicular pattern of the axillary nerve is quite variable, Sunderland (1968) noted that the number of funiculi ranged from 1 to 15. In the axilla there is usually a single large motor funiculus accompanied by fine satellites.

The axillary nerve supplies the teres minor and the deltoid. Paralysis of the nerve leads to loss of abduction of the arm. Its sensory fibers supply the skin on the posterolateral aspect of the shoulder.

The axillary nerve can be injured by dislocation of the glenohumeral joint and by fractures of the surgical neck, and it can be compressed in the axilla, e.g., by crutches. It is at risk during surgery when the shoulder joint or proximal humerus is approached from the posterior or lateral aspect.

RADIAL NERVE PALSY

The radial nerve is a continuation of the posterior cord. Its roots emerge at the C6, C7, C8, and T1 levels. Lying at first behind the axillary artery, it runs distally in the arm by winding around the posterior aspect of the humerus from medial to lateral (Fig. 6–2). It continues in the lateral bicipital groove in the cubital fossa. As it reaches the humeroradial joint line, the radial nerve divides into two terminal branches (Fig. 6–3)—the anterior sensory branch, which runs into the forearm under the brachioradialis lateral to the radial artery, and a posterior motor branch, the posterior interosseous nerve, which penetrates the supinator muscle by passing under the arcade of Frohse (Frohse

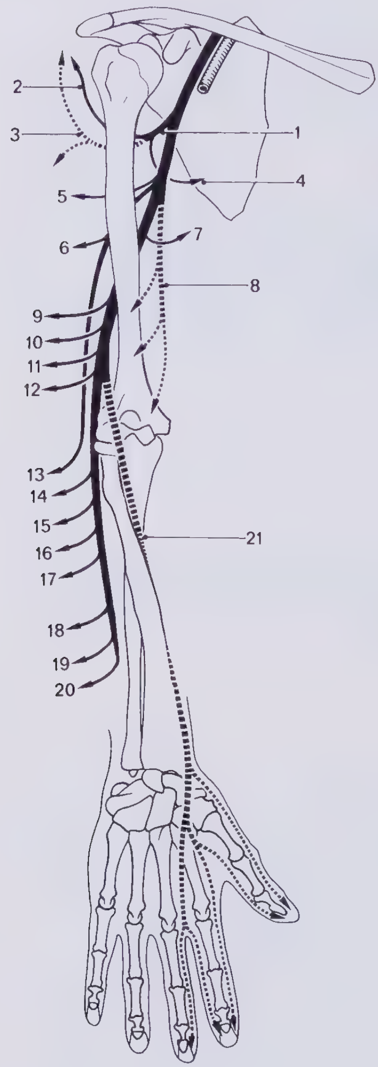

Figure 6–1. The radial and axillary nerves; muscles supplied and cutaneous distribution. The forearm is pronated. 1, Axillary nerve. 2, Deltoid. 3, Cutaneous branch to shoulder. 4, Teres minor. 5, Triceps (long). 6, Triceps (lateral). 7, Triceps (medial). 8, Medial cutaneous branch. 9, Brachioradialis. 10, Extensor carpi radialis longus. 11, Extensor carpi radialis brevis. 12, Supinator. 13, Anconeus. 14, Extensor digitorum communis. 15, Extensor digitorum to fifth digit. 16, Extensor carpi ulnaris. 17, Abductor pollicis longus. 18, Extensor pollicis brevis. 19, Extensor pollicis longus. 20, Extensor indicis proprius. 21, Anterior sensory branch. The sensory branches are shown as dotted lines.

and Frankel, 1908; Fig. 6–4). This arcade is fibrous in about one-third of the cases and may compress the nerve. The nerve winds around the neck of the radius (between the two heads of the supinator). In 25 per cent of the cases it lies flush against the periosteum for about 3 cm. (bare area) when the forearm is supinated; it is more vulnerable at this level (Spinner, 1978). The nerve then emerges from the supinator in the posterior compartment of the forearm. After giving off branches to all the muscles in this compartment, it runs along the posterior aspect of the interosseous membrane and sends sensory branches to the wrist and carpometacarpal joint.

The radial nerve supplies all the extensors of the elbow, the wrist, and the fingers. The two interphalangeal joints of the fingers can also be extended by the interosseous muscles.

By contrast, its sensory territory is relatively limited (the lateral half of the dorsum of the hand), but the autonomous zone is restricted to the dorsal aspect of the first interosseous space, so that sensory nerve palsy is functionally insignificant. However, sectioning of the small sensory branches of the radial nerve at the wrist can give rise to painful neuromas.

In the arm the anterior (superficial) and posterior (interosseous) divisions of the radial nerve can be traced as funiculi for 7.2 to 9.0 cm. above their point of division. The single funiculus of the posterior interosseous nerve branches 35 mm. distal to its origin, giving a branch to the supinator.

On the motor side, radial palsy results in paralysis of the triceps (rare after injury because the fibers supplying this muscle arise high in the axilla) and paralysis of the supinator (partially compensated for functionally by the biceps and by shoulder movements). By contrast, three movements that are essential to hand function are lost and cannot be compensated for—extension of the wrist (all three wrist extensors are supplied by the radial nerve), extension and

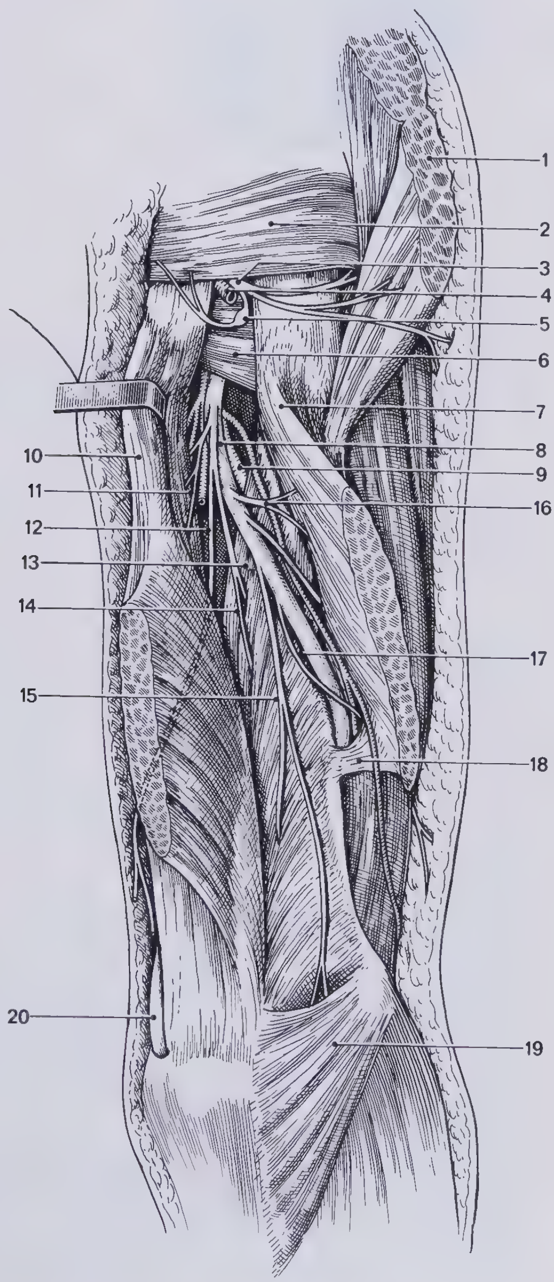

Figure 6–2. Dissection of the posterior arm to show the axillary and radial nerves (right arm). 1, Deltoid muscle (posterior part reflected anteriorly). 2, Teres minor. 3, Axillary nerve emerging with posterior humeral circumflex artery (4) through the quadrilateral space. 5, Branch to teres minor, showing a ganglion. 6, Teres major. 7, Lateral head of triceps. 8, Radial nerve with the profunda brachii artery (9). 10, Long head of triceps. 11, Nerve to long head of triceps. 12, Medial cutaneous nerve of arm. 13, Short head of triceps. 14, Superior nerve to short head of triceps. 15, Inferior nerve to short head of triceps and anconeus. 16, Superior nerve to lateral head of triceps. 17, Inferior nerve to lateral head of triceps. 18, Lateral intermuscular septum. 19, Anconeus. 20, Ulnar nerve.

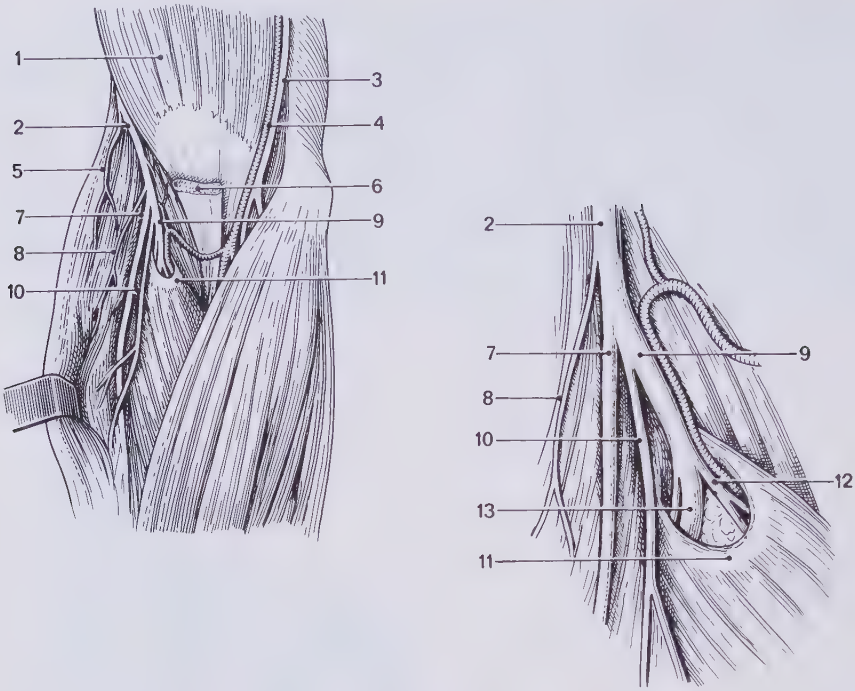

Figure 6–3. The radial nerve at the level of the elbow. 1, Brachialis. 2, Radial nerve. 3, Median nerve. 4, Brachial artery. 5, Branch to brachioradialis. 6, Cut end of biceps tendon. 7, Superficial branch of radial nerve. 8, Branch to extensor carpi radialis longus. 9, Posterior motor branch of radial nerve. 10, Branch to extensor carpi radialis brevis. 11, Arcade of Frohse. 12, Branches to supinator. 13, Posterior interosseus nerve.

retroposition of the thumb (brought about by the extensor pollicis longus, abductor pollicis longus, and extensor pollicis brevis), and extension of the metacarpophalangeal joints of the fingers.

The close anatomical relationship of the radial nerve with the humeral shaft accounts for the high incidence of radial nerve injuries in fractures of the humerus.

As it crosses the spiral groove on the posterior aspect of the humerus, the nerve is not in contact with the bone. They are kept apart by thin sheets of muscle. They come into direct contact only at the lateral supracondylar border of the bone. At this level the nerve crosses the inextensible posterior intermuscular septum to enter the lateral bicipital groove; it is somewhat stretched at this point, and lack of mobility accounts for its vulnerability in humeral fractures (Holstein and Lewis, 1963).

Primary radial nerve palsies are commonly associated with fractures of the middle and distal thirds of the humeral shaft. These fractures are usually characterized by lateral angulation and overriding of the distal fragment. Seddon (1943) demonstrated that actual division of the nerve is rare. Thus, emergency treatment should be directed at proper closed management of the fracture with frequent evaluation of the status of the nerve injury before any operative intervention is undertaken.

This conservative approach is now being reconsidered. Vichard (1982) found that in more than 25 per cent of his cases of radial nerve palsy associated with a humeral fracture there was either complete disruption or significant entrapment of the nerve. The advantage of early operative intervention in these cases is obvious. It is possible that this increase in the severity of the

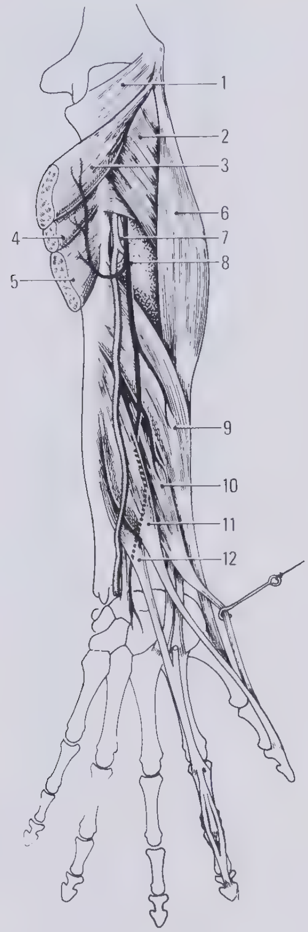

Figure 6–4. The posterior compartments of the forearm showing the posterior interosseous nerve and its branches (deep planes only). 1, Anconeus. 2, Supinator. 3, Extensor digitorum. 4, Extensor digiti minimi. 5, Extensor carpi ulnaris. 6, Brachioradialis. 7, Posterior interosseous artery. 8, Motor branch of radial nerve (posterior interosseous). 9, Abductor pollicis longus. 10, Extensor pollicis brevis. 11, Extensor pollicis longus. 12, Extensor indicis.

radial nerve lesions is a result of the frequent association today of severe multisystem trauma with this injury. Iatrogenic radial nerve palsy is a separate problem. It results from the technique of closed reduction or surgical exposure and is unrelated to the type of fracture.

MUSCULOCUTANEOUS NERVE PALSY

The musculocutaneous nerve arises from the lateral cord of the brachial plexus lateral to the axillary artery. It enters the arm by piercing the coracobrachialis from medial to lateral and runs between the biceps anteriorly and the brachialis posteriorly to the lateral bicipital groove of the cubital fossa (Fig. 6–5). It then becomes superficial on the lateral side of the biceps tendon and medial cephalic vein, and as the lateral cutaneous nerve of the forearm divides into its two terminal branches—an anterior branch for the anterolateral aspect of the forearm and a posterior branch that supplies the posterolateral skin.

The collateral motor branches supply the coracobrachialis, biceps, and brachialis. Lesions of these branches result in considerable impairment of elbow flexion. Loss of the adductor action of the coracobrachialis can be compensated for by the pectoralis major.

The segment of the nerve traversing the coracobrachialis muscle is impos-

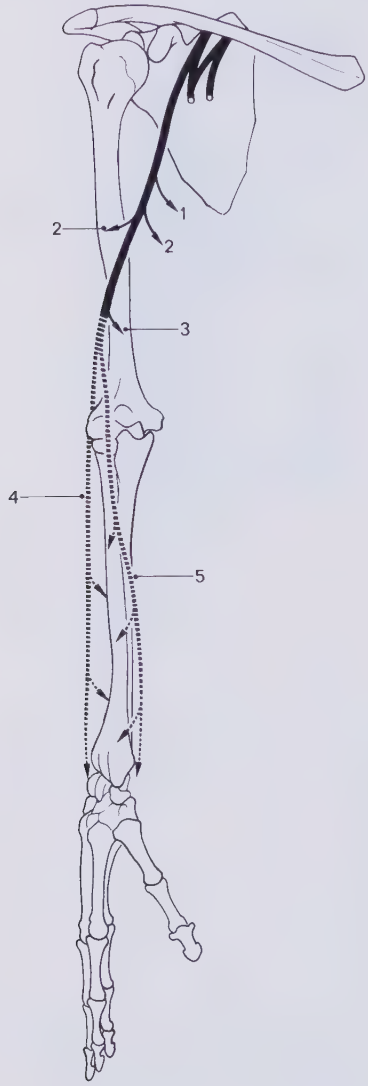

Figure 6–5. The musculocutaneous nerve; muscles supplied and cutaneous distribution. 1, Coracobrachial branch. 2, Biceps brachii. 3, Anterior brachial branch. 4, Posterior branch (sensory). 5, Anterior branch (sensory). The sensory branches are shown as dotted lines.

sible to dissect. The terminal branch, the lateral cutaneous nerve of the forearm, has a similar pattern.

MEDIAN NERVE PALSY

The median nerve arises by two roots—one from the lateral cord of the brachial plexus (C6, C7) and the other from the medial cord (C8, T1). The two roots arch around the axillary artery and join anterior to it (Fig. 6–6). Thus formed, the median nerve runs distally in the anteromedial compartment of the arm. In the cubital fossa the nerve lies medial to the artery, covered by the bicipital aponeurosis, and passes between the two heads of the pronator teres and under the fibrous arch, joining the two heads of the flexor digitorum superficialis. It crosses anterior to the ulnar artery and enters the anterior compartment of the forearm, closely bound to the deep surface of the flexor digitorum superficialis, within the muscle sheath (Fig. 6–7). As the muscle

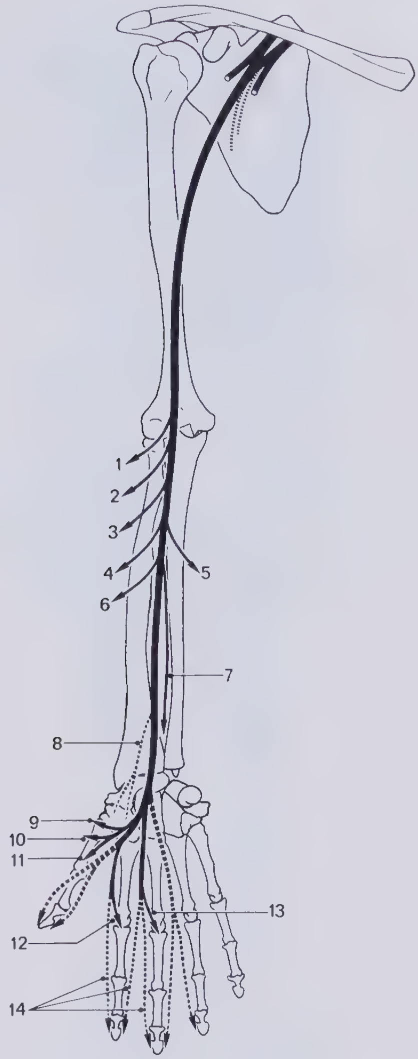

Figure 6–6. The median nerve; muscles supplied and cutaneous distribution. 1, Pronator teres. 2, Palmaris longus. 3, Palmaris brevis. 4, Flexor digitorum superficialis. 5, Flexor digitorum profundus to second and third digits. 6, Flexor pollicis longus. 7, Pronator quadratus. 8, Palmar cutaneous branch. 9, Abductor pollicis brevis. 10, Superficial branch to flexor pollicis brevis. 11, Opponens pollicis. 12, First lumbrical. 13, Second lumbrical. 14, Digital nerves (sensory). The sensory branches are shown as dotted lines.

changes to tendon in the lower half of the forearm, the median nerve runs at first lateral to the index tendon and then anterior to it and lateral to the tendon of the middle finger. It runs under the flexor retinaculum, and as it emerges from the carpal tunnel, it divides into its terminal branches to the lateral thenar muscles, the radial two lumbrical muscles, the skin of the radial half of the palm and palmar skin of three and one-half digits, and the skin covering the dorsum of the distal and medial phalanges of the radial three and one-half digits.

The median nerve gives off numerous motor branches to the anterior forearm muscles. Above the elbow the medial epicondylar branch to the pronator teres arises. It accompanies the anterior interosseous artery in the gap between the flexor pollicis longus and flexor digitorum profundus and sends branches to both muscles (only the lateral heads of the flexor profundus) and to the pronator quadratus.

The median nerve can be compressed at several points along its course—between the heads of pronator teres, in the fibrous bridge between the heads of the flexor digitorum superficialis, and of course within the carpal tunnel.

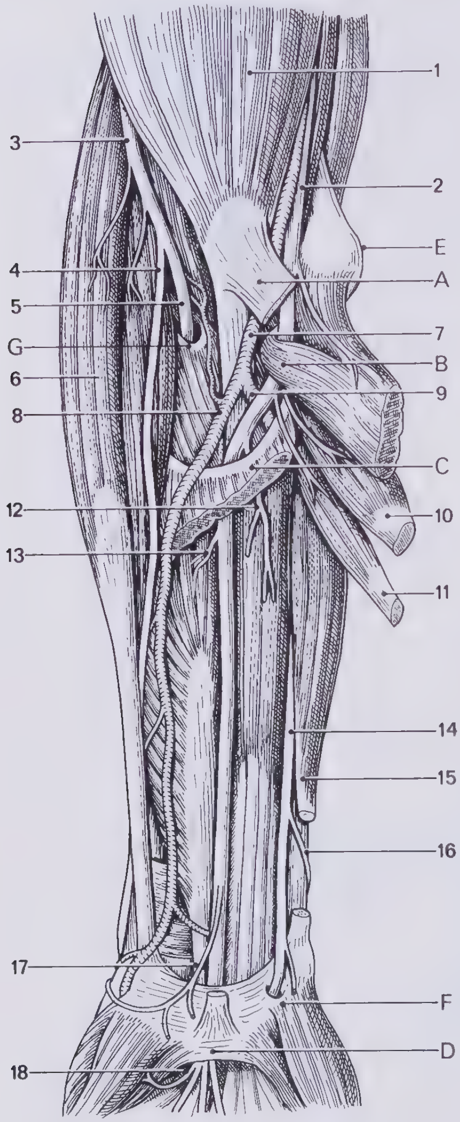

Figure 6–7. Dissection of the anterior aspect of the forearm to show the median nerve, radial nerve, and ulnar nerve. The common sites of compression of the three nerves are shown. 1, Biceps brachii. 2, Median nerve. 3, Radial nerve. 4, Sensory branch of radial nerve. 5, Motor branch of radial nerve. 6, Brachioradialis. 7, Brachial artery. 8, Radial artery. 9, Ulnar artery. 10, Flexor carpi radialis. 11, Palmaris longus. 12, Branch of anterior interosseous nerve to flexor digitorum profundus to index and middle fingers. 13, Branch of anterior interosseous nerve to flexor pollicis longus. 14, Ulnar nerve. 15, Flexor carpi ulnaris. 16, Dorsal cutaneous branch of ulnar nerve. 17, Palmar cutaneous branch of the median nerve. 18, Thenar branch of median nerve.

Common sites of nerve compression in the forearm. Median nerve: A, Expansion of biceps. B, Two heads of pronator teres. C, Flexor digitorum sublimis. D, Carpal tunnel. Ulnar nerve: E, Medial epicondylar groove. F, Guyon's canal. Radial nerve: G, Arcade of Frohse.

The fascicular anatomy of the median nerve is relatively constant in the forearm, presenting clearly defined bundles.

The recurrent thenar branch is composed of two fascicles. It joins the nerve on its volar-radial side and can be traced proximally for about 70 mm.

The palmar cutaneous branch also presents two separate bundles; they can be traced proximally for about 190 mm.

The flexor digitorum superficialis branches are variable.

The anterior interosseous nerve can be traced for about 150 mm. In its intraneural course it gives off the motor branch to the flexor carpi radialis.

The pronator teres branch dissects within the nerve for 100 mm. without any interfascicular connections.

During its superficial course across the wrist, the median nerve is particularly exposed to trauma; hence the high incidence of low median nerve palsies. These result in the loss of the most essential function of the nerve, sensibility of the prehensile zone, which includes the all important pulp skin of the thumb and index and middle fingers.

It is relatively easier to compensate for paralysis of the lateral thenar

muscles, because the flexor pollicis brevis is partly or wholly supplied by the ulnar nerve and therefore is frequently spared.

Sectioning of the median nerve above the elbow produces, in addition to the intrinsic lesions of the hand already described, paralysis of the flexor pollicis longus, flexor digitorum superficialis, and the lateral half of the flexor profundus, resulting in loss of flexion of the distal phalanges of the thumb, the index finger, and sometimes the middle finger. Pronation of the forearm is usually preserved because the high branches to the pronator teres are given off above the elbow. More proximal lesions of the median nerve severely impair pronation.

ULNAR NERVE PALSY

The ulnar nerve arises from the medial cord of the brachial plexus and lies at this point medial to the medial cord contribution to the median nerve. Its fibers come from the C7, C8, and T1 roots. It runs medial to the humeral artery, goes through the medial intermuscular septum, and passes between the medial epicondyle of the humerus and the olecranon (Fig. 6–8). It enters the

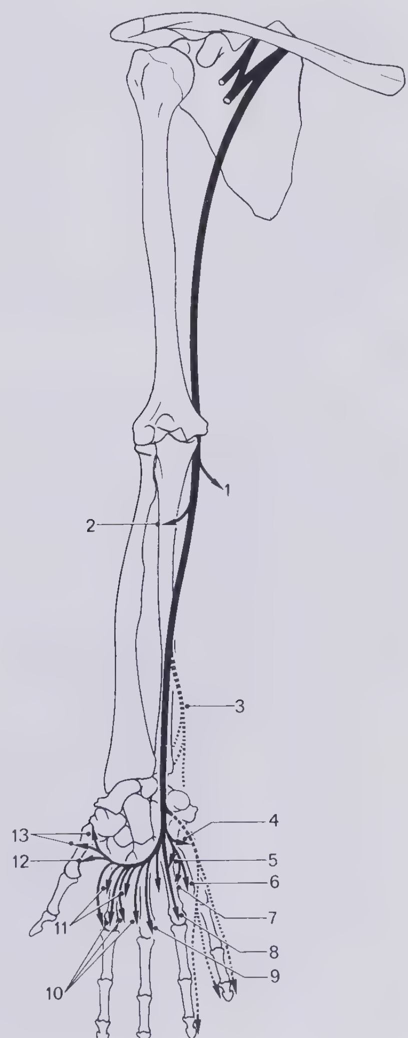

Figure 6–8. The ulnar nerve; muscles supplied and cutaneous distribution. 1, Branch to flexor carpi ulnaris. 2, Branch to flexor digitorum profundus supplying fourth and fifth digits. 3, Dorsal cutaneous branch. 4, Palmar cutaneous branch. 5, Branch to abductor digiti minimi. 6, Branch to opponens digiti minimi. 7, Branch to flexor digiti minimi. 8, Fourth lumbrical branch. 9, Third lumbrical branch. 10, Branch to palmar interosseous muscles. 11, Branch to dorsal interosseous muscles. 12, Deep branch to flexor pollicis brevis. 13, Branch to adductor pollicis. The sensory branches are shown as dotted lines.

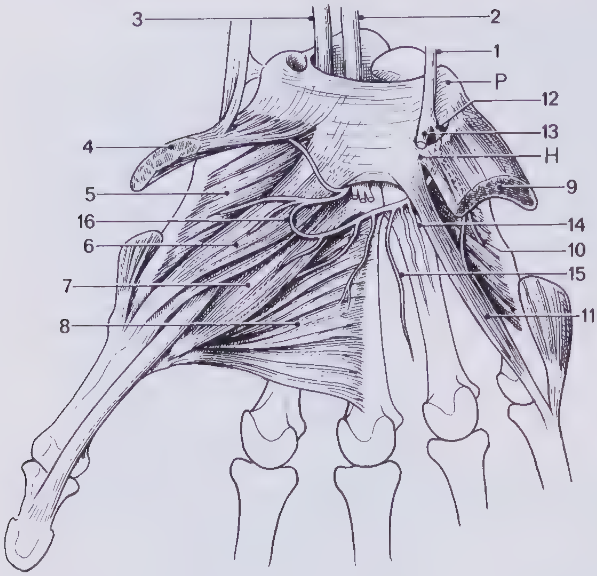

Figure 6–9. Dissection of the palm to show the deep branch of the ulnar nerve. 1, Ulnar nerve. 2, Median nerve. 3, Flexor pollicis longus. 4, Abductor pollicis brevis. 5, Opponens pollicis. 6, Flexor pollicis brevis. 7, Adductor pollicis, oblique fibers. 8, Adductor pollicis, transverse fibers. 9, Abductor digiti minimi. 10, Opponens digiti minimi. 11, Flexor digiti minimi. 12, Motor branch of ulnar nerve. 13, Sensory branch of ulnar nerve. 14, Branches to ulnar two lumbrical muscles. 15, Branches to interosseous muscles (only one shown). 16, Anastomosis between thenar branch of median nerve and deep motor branch of ulnar nerve (anastomosis of Riche and Cannieu). P, Pisiform. H, Hamate.

forearm between the humeral and ulnar origins of the flexor carpi ulnaris and descends within the anteromedial compartment of the forearm under cover of the flexor carpi ulnaris. At the wrist, lying on the medial side of the ulnar artery, it runs with the latter, in the so-called Guyon osseofibrous canal (distinct from the carpal tunnel). Just distal to the pisiform it divides into its two terminal branches, the superficial sensory branch, which supplies the medial skin of the hand, and the deep motor branch, which winds around the hook of the hamate, crosses the sharp lower border of the opponens digiti minimi muscle, and, under cover of the deep flexor tendons, reaches the adductor pollicis and flexor pollicis brevis muscles on the lateral side of the hand (Fig. 6–9).

The ulnar nerve supplies the flexor carpi ulnaris and the two ulnar heads of the flexor digitorum profundus. In the lower third of the forearm it gives off the dorsal cutaneous branch, which supplies the skin of the ulnar half of the dorsum of the hand. Between them the median and the ulnar nerves supply all the intrinsic muscles of the hand; the deep terminal branch of the ulnar nerve sends fibers to all the intrinsic muscles (except the two lateral lumbricals), to the adductor pollicis, and to the deep head of the flexor pollicis brevis. In fact the respective territories of the median and ulnar nerves are poorly defined. Anastomoses occur in the forearm (Martin-Gruber anastomosis) in 15 per cent of the cases according to Mannerfelt (1966) and in the palm (anastomoses of Riche and Cannieu [Riche, 1897]), which explain the frequent anomalies of distribution (Fig. 6–10).

The ulnar nerve can be compressed at several points:

1. In the lower third of the arm, the nerve enters the posterior compartment by passing through an osseofibrous foramen (Fig. 6–11). This is formed laterally by the medial intermuscular septum (which is attached to the humerus), above by a fibrous expansion of the coracobrachialis, and medially by the medial head of the triceps. Distally the foramen may be narrowed by inconstant insertions of the triceps, which form "Struthers' arcade" (Struthers, 1854).

2. At the elbow the nerve passes through a narrow channel between the epicondyle and the olecranon where it may be compressed by the bone or joint

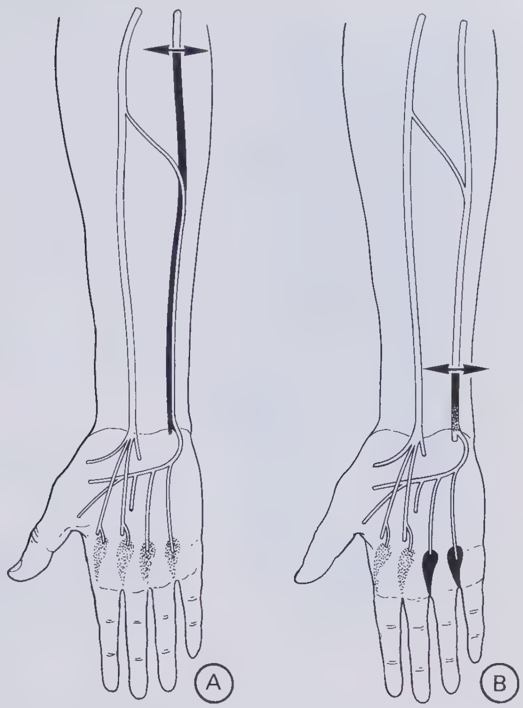

Figure 6–10. Diagram to show the Martin-Gruber anastomosis between the median and ulnar nerves in the forearm. In high lesions of the ulnar nerve (*A*), the anastomosis from the median nerve can result in prevention of paralysis of the ulnar innervated intrinsic muscles. In lesions of the ulnar nerve distal to the anastomosis (*B*), this will not occur.

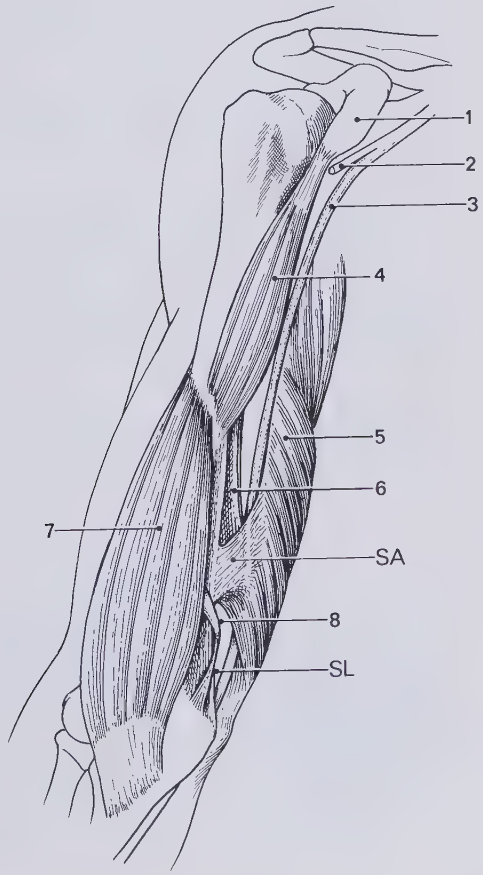

Figure 6–11. Dissection to show the ulnar nerve in the arm and its common sites of compression. 1, Coracoid process. 2, Musculocutaneous nerve. 3, Ulnar nerve. 4, Coracobrachialis. 5, Medial head of triceps. 6, Medial intermuscular septum. 7, Brachialis. 8, Supracondylar spur. SA, Struther's arcade. SL, Struther's ligament.

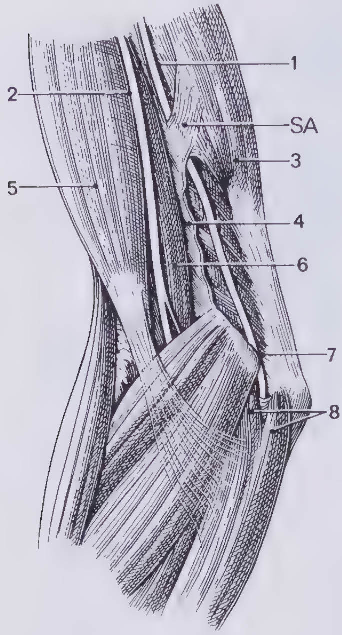

Figure 6–12. The ulnar nerve at the elbow. 1, Ulnar nerve. 2, Median nerve. 3, Triceps. 4, Medial intermuscular septum. 5, Biceps. 6, Brachialis. 7, Medial epicondylar groove. 8, Two heads of flexor carpi ulnaris. SA, Struther's arcade.

(Fig. 6–12). Next the nerve runs between the humeral and ulnar heads of the flexor carpi ulnaris under a fibrous arcade, which must be divided to relieve compression at that level (Osborne, 1970).

3. The nerve also can be compressed in the wrist as it courses through Guyon's canal whose floor is formed by the flexor retinaculum (inserted on the pisiform) and its roof by an expansion of the flexor carpi ulnaris (Fig. 6–13).

The deep terminal branch dives under the fibrous band that stretches from the pisiform to the hook of the hamate, from which arise the abductor and flexor digiti minimi brevis.

The ulnar nerve is most vulnerable at the elbow and at the wrist.

Funicular Anatomy. The distal part of the ulnar nerve can be microdissected easily. The dorsal cutaneous branch forms an independent fascicle that can be traced proximally well above the epicondyle. Jabaley et al. (1980) suggested the use of this branch as a graft in cases in which it is considered expendable.

Sensory ulnar palsy affects both the palmar and the dorsal aspects of the ulnar half of the hand. The autonomous zone of the ulnar nerve is limited to the skin of the distal two phalanges of the little finger.

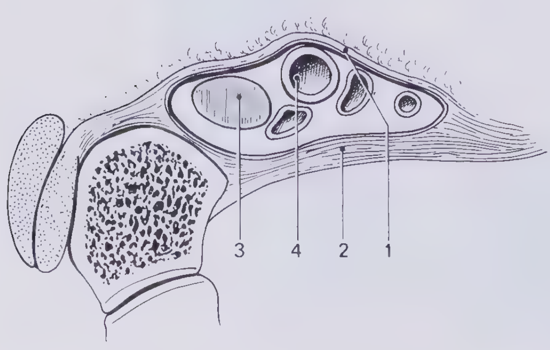

Figure 6–13. The space of Guyon (transverse section). 1, Volar ligament of wrist. 2, Flexor retinaculum. 3, Ulnar nerve. 4, Ulnar artery.

Motor ulnar palsy, by contrast, has far more functional consequences (Table 6–1). Distal ulnar nerve lesions produce the classic claw deformity of the fingers. There is wasting of the interosseous muscles and thenar and hypothenar eminences, as well as hyperextension of the metacarpophalangeal joints and flexion of the interphalangeal joints. This posture is less obvious in the index and middle fingers because the lateral lumbrical muscles, supplied by the median nerve, remain functional. The claw is more marked if the deep flexor retains its tonicity. In the thumb, paralysis of the adductor causes a significant loss of pinch strength. Furthermore, in pinch, the distal phalanx of the thumb assumes a position of flexion (Froment's sign), and the proximal phalanx hyperextends (Jeanne's sign) when the flexor pollicis brevis is also paralyzed. In terminal thumb-index pinch, the patient cannot make an O with the two digits (Bunnell, 1956); the metacarpophalangeal joints have a tendency

Table 6–1. SYMPTOMS AND SIGNS IN ULNAR NERVE PARALYSIS*

Original Description by	Year	Symptoms and Signs
Duchenne	1867	Clawing of the ring and little fingers. The little finger cannot be adducted to the ring finger. Inability to play high notes on the violin because the flexor carpi ulnaris and opponens digiti quinti are paralyzed and there is loss of sensibility of the little finger.
Jeanne	1915	Hyperextension of the metacarpophalangeal joint of the thumb in pinch grip; Jeanne's sign.
Froment	1915	Pronounced flexion of the interphalangeal joint of the thumb during adduction toward the index finger; Froment's sign.
Masse	1916	Flattening of the metacarpal arch.
André-Thomas	1917	The wrist tends to fall into volar flexion during action of the extensors of the middle finger.
Pollock	1919	Inability to flex the distal phalanx of the fifth finger.
Pitres-Testut	1925	The transverse diameter of the hand is decreased. Radial-ulnar abduction of the metacarpophalangeal joint of the middle finger is impossible. Inability to shape the hand to a cone.
Wartenberg	1939	Inability to adduct the extended little finger to the extended ring finger; Wartenberg's sign.
Sunderland	1944	Inability to rotate, oppose, or supinate the little finger toward the thumb; Sunderland's sign.
Fay	1954	Inability of the thumb to reach the little finger in true opposition (probably a misinterpretation of the author because the little finger cannot always reach the thumb in cases of paralysis of the opponens of the little finger).
Bunnell	1956	The thumb no longer pinches against the index finger to make a full circle.
Egawa	1959	Inability of the flexed middle finger to abduct radially and ulnarly and to rotate at the metacarpophalangeal joint.
Mumenthaler	1961	On abduction of the little finger against resistance, no normal dimple appears in the hypothenar region because of paresis of the palmaris brevis musculature.
Mannerfelt	1966	Hyperflexion sign. Thumb: Interphalangeal joint flexed; metacarpophalangeal joint slightly hyperextended. The thumb is markedly supinated. Index finger: With increasing force in the collapsed pinching grip, a flexion position (often more than 90 degrees) of the proximal interphalangeal joint is seen. The distal interphalangeal joint is hyperextended, and the radial part of the pulp slides in a proximal direction along the ulnar part of the thumb.

*Adapted from Mannerfelt, L.: Studies on the hand in ulnar nerve paralysis. A clinical-experimental investigation in normal and anomalous innervation. Acta Orthop. Scand., Suppl. 87, 1966.

Figure 6–14. Ulnar palsy (on the right), showing Froment's sign in the thumb and hyperflexion of the proximal interphalangeal joint of the index finger. (Courtesy Dr. L. Mannerfelt.)

to hyperextend and the maximal interphalangeal joint of the index finger tends to hyperflex (Mannerfelt, 1966; Fig. 6–14). The deformity is less marked in proximal lesions because the flexor profundus is also paralyzed. In ulnar nerve lesions at the elbow, the flexor carpi ulnaris is usually spared, in part or in toto. The clinical features are different in partial lesions and in combined lesions.

THE SIGNS OF NERVE REGENERATION

Two concepts must be kept in mind: Recovery occurs from proximal to distal, and the signs of sensory recovery precede those of voluntary motor activity.

TINEL'S SIGN

The first detectable clinical sign of recovery is Tinel's sign. Percutaneous percussion of the nerve trunk distal to the lesion (as far as the level of axonal regeneration) produces a "pins and needles" sensation distally in the territory of the distribution of the cutaneous nerve. This sign was described in the same year (1915) by Hoffmann and by Tinel. In an article that has now become a classic, Tinel distinguished between peripheral paresthesia, a sign of axonal regeneration, and local pain, which indicates irritation of the nerve. He emphasized the significance of this test in monitoring regeneration of the nerve, but stressed that the sign is neither constant nor easy to interpret.

Technique

Percussion must be gentle, done with the tip of the finger or, more accurately, with the blunt tip of a felt pen or a rubber eraser. One should avoid inaccurate mechanical stimulation with large objects and restrict percussion to

the course of the nerve. Most clinicians percuss from a distal point proximally along the course of the nerve trunk until they reach the site at which percussion triggers paresthesias. Others work in reverse from the site of the lesion downward until the induced sensation disappears. The reaction can be compared to that of a weak electric current, unpleasant but not painful. It is important to remember that the sensation is felt peripherally, in the area of the cutaneous distribution of the nerve, and differs from the sometimes painful sensation felt at the point of direct pressure on the nerve caused by neuroma formation or by irritation of the pain fibers. A similar peripheral reaction can be obtained by electrical stimulation using a cathode 1 cm. in diameter applied to a point over the course of a nerve, and a broader anode at some other point of the body (Moldaver, 1978). Even when a continuous stimulus is applied, the sensation is felt as an intermittent vibration.

Clinical Significance of Tinel's Sign

The pins and needles sensation felt on percussion is caused by regeneration of the sensory axons, which are very sensitive to pressure. The sign would therefore indicate a favorable prognosis and enables one to follow the progress of the patient. Only percussion of the tactile fibers triggers the pins and needles sensation, not those transmitting pain, heat, and cold.

Changes in the response to Tinel's test enable one to assess the progress of axonal regrowth. It varies from person to person and is faster in the proximal part of the limb than at the extremities. It is faster after spontaneous healing than after nerve suturing. In the latter case it is usually 1 to 2 mm. per day (Jung, 1941; Sunderland and Bradley, 1952). A positive response over a long segment of nerve suggests unequal rates of growth of various tactile fibers.

The sign fell into disrepute because it was sometimes absent when a nerve was in fact regenerating and at other times was positive when exploration showed a total absence of continuity between the nerve ends (Woodhall and Beebe, 1956). By contrast, other authors attach great significance to the test (Henderson, 1948).

Tinel himself has pointed out that the sign is absent in certain circumstances:

1. In the early stages following the injury or nerve suturing. The sign, according to Tinel, appears only four to six weeks after the injury. In fact this period is very variable, because axonal growth depends on a number of factors, but it can be said that the time is roughly proportional to the severity of the lesion.
2. The sign may be difficult to elicit if the nerve lies deep to a large mass of muscle.
3. The sign cannot be demonstrated if the lesion is proximal to the posterior root ganglion.

The prognostic value of Tinel's sign is not absolute because not all the regenerating tactile fibers necessarily recover. Some lose their way; others just stop growing. And even if they continue growing within the nerve sheath, they may follow a wrong route. Thus, a false positive Tinel sign is elicited when sensory fibers grow into motor sheaths.

Finally the test has no quantitative value, for it can be positive with only a few fibers regenerating; hence its limited functional significance.

In spite of all these limitations, the sign is clinically useful if, within a few weeks after the injury or suturing, light percussion distal to the lesion triggers

the pins and needles sensation peripherally, and if in the course of the following weeks percussion at the same level produces a weak response that becomes stronger if tapping is done more distally. This appears to confirm axonal growth. Interrrupted progress must be regarded as alarming, and if this persists and the absence of other signs of regeneration (to be discussed) confirms this, surgical exploration is indicated. Steady distal progression of Tinel's sign, unless contradicted by other factors, suggests a good prognosis, even though little information concerning the functional quality of reinnervation is provided.

Too much should not be expected of Tinel's sign, and it must be interpreted only in conjunction with other clinical findings.

OTHER SIGNS OF REGENERATION

Motor recovery is always slower than sensory recovery. The first sign of motor recovery is the regression of the atrophy in the territory normally supplied by the injured nerve. Later a weak contraction can be detected in the first muscle supplied by the nerve distal to the lesion. The contraction, however, is not powerful enough to produce movement or to overcome gravity.

Precise electromyographic studies can demonstrate signs of motor recovery before any clinical signs of activity can be demonstrated, provided the electrodes are placed close to the point where the nerve penetrates the muscle.

It should be pointed out that these early signs of nerve regeneration, both clinical and electromyographic, are of limited prognostic value; they suggest a favorable outcome but offer no guarantee of functional recovery.

Although it is necessary to detect the early signs of nerve regeneration, it is equally essential to follow its progress. Regeneration can be halted at any stage, and there is frequently a marked difference between motor and sensory recovery. As far as the latter is concerned, pain usually appears before touch. Sensation returns first to the proximal margin of the anesthetic zone. It is important to record the interval between the reappearance of contraction in the first muscle supplied distal to the nerve suture and in the next one. Regeneration can slow down or even stop before reaching the extremity of the limb. All these variations make the decision for and timing of secondary repairs very difficult.

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Index

Page numbers printed in *italic* type refer to illustrations and tables.

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